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MESOZOIC CHANGES IN THE FAUNAL GEOGRAPHY OF CALIFORNIA.

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INTRODUCTION.

THERE is probably no region where the successive faunas have been a genetic series. With each new set of rocks species, genera, families appear without local forerunners and disappear without leaving local descendants. Thus the distribution of

genera varies greatly in successive periods. These changes have been due to migration; each rising of a seacoast, or transgression of sea on land areas, or connection of basins that before were separated, has added to the confusion of faunas, bringing in new elements, while many of the old were forced to migrate, or else were unable to survive the new conditions and increased natural competition with vigorous immigrants.

Marine invertebrates migrate chiefly through their young, and along shore lines, where the successive generations can find the same conditions suitable to their perpetuation, and the young are especially sensitive to changes in temperature and food-supply. Therefore marine currents along continental borders are very favorable to migration, since by them the same conditions necessary for life are spread far out of their usual range.

If the naturalist would trace out the life history of genera and species, he must not confine his studies to a single region, for there the history is made up of disconnected episodes. He must seek the regions from which the faunas came and follow out their migrations into regions to which they departed, must find out what regions contributed certain new elements to the population and must learn the order of appearance of a fauna in different parts of the earth. In this way alone can he get a true idea of the changes which forms have suffered, and the reason of these changes, the mutual working of the laws of natural selection and adaptation to surroundings. In this way, too, he can get a true history of the inhabitants of the earth, and of the changes in physical geography at various periods, the primary object of geologic investigation.

The study of the faunal relations of the various series of sedimentary rocks of California has proved exceedingly interesting and has thrown much light on past changes in physical geography. Some of the facts obtained seem to conflict with the theory of the permanency of continental plateaux and oceanic troughs.

The writer has, therefore, undertaken to outline the faunal relations which California had with various regions during differ-

ent periods of geologic history, and the probable changes in physical geography that accompanied and caused this shifting of relations. The Mesozoic era has been taken as a basis because the faunas of that time are better known, and because the physical geography of that time has been better worked out all over the earth. But the changes which preceded the Mesozoic era will also be outlined as far as they are known. And since California is intimately connected with other regions of the West Coast, these regions will also be considered in so far as they concern California.

PRE-CARBONIFEROUS RELATIONS.

Cambrian and Silurian.—The Cambrian and Silurian of California, as described by Professor C. D. Walcott[1] in the papers cited below, are too little known for any opinion about them to be decisive; they are, however, probably like the Cambrian and Silurian as it is known in Nevada and the West in general.

Devonian.—In California the Devonian is little known, having been described by J. S. Diller and Charles Schuchert[2] from only a few places in Shasta and Siskiyou counties, and the forms that occur there give little clue to the affinities with other regions. But from the study of the faunas of other parts of America we get some light on the geography of the Devonian.

The work of Dr. A. Ulrich[3] has made it clear that during the Lower and Middle Devonian the faunas of North America were closely related to those of Bolivia, Brazil, the Falkland Islands, and South Africa, but that they were different from those of Europe. But Professor H. S. Williams[4] has shown that at the beginning of the Upper Devonian in North America there came in many species whose ancestors are not found in the Middle Devonian of that region. This fauna, however, is closely related

[1] Am. Jour. Sci., III. Series. Vol. XLIX., pp. 141–144, and Bull. Geol. Soc. Amer., Vol. III., p. 376.

[2] Am. Jour. Sci., III. Series, Vol. XLVII., pp. 416–422.

[3] Beiträge zur Geol. und Pal. von Südamerika, I. Paläozoische Versteinerungen aus Bolivien.

[4] Bull. Geol. Soc. Amer., Vol. I., Cuboides Zone and its Fauna, and Proc. A. A. A. S., 1892, Sec. E., Address; Scope of Paleont. and its Value to Geologists.

to that of Europe and Asia while quite different from that of the southern regions.

This striking change in the faunal relations of North America means something more than a mere migration; it means that in Lower and Middle Devonian times some barrier cut off the European and Asiatic faunas from those of America, and that in the Upper Devonian this barrier was removed while one was interposed between the northern and the southern regions. Professor W. Waagen[1] has shown that this continued during the Carboniferous and Permian.

CARBONIFEROUS FAUNAS.

Lower Carboniferous.—In a previous paper[2] the writer has shown that the Lower Carboniferous fauna of California was derived directly from the preceding Devonian, since so many species that in the Mississippi Valley or eastern region would be considered characteristic of the Devonian still survive. This survival has been used by Professor H. S. Williams,[3] and the writer,[4] to show that the reappearances of older forms in younger rocks have been due to migrations consequent upon the shifting of physical barriers.

Affinities of the fauna.—The Lower Carboniferous, or Baird Shales, fauna of California is intermediate in character, as it is in geographic position between the eastern American and the Russian and Asiatic. It differs from the typical American fauna in the survival of so many Devonian types and the presence of some Eurasian elements. It belongs to the zone of *Productus giganteus* or the lower part of C_1 of the Russian section.

Upper Carboniferous.—The Upper Carboniferous fauna of California seems to have been developed directly out of older species in the same region, since there is known no complication of elements brought in by the migration from outside the Pacific Car-

[1] Palæontologia Indica, Salt Range Fossils, Geological Results.

[2] JOUR. GEOL., Vol. II., No. 6, The Metamorphic Series of Shasta County, California.

[3] Am. Jour. Sci., III. Series, Vol. XLIX., pp. 94-101.

[4] JOUR. GEOL., Vol II., p. 198, and Vol. II., p. 598.

boniferous region. Again here we see the intermediate characteristic between the eastern American and Eurasian faunas, but the affinities are closer with the latter.

The McCloud limestone corresponds to the upper part of C_1, and the lower part of C_2 of the Russian section. The upper part of the McCloud limestone is, therefore, homotaxial with the zone of *Omphalotrochus whitneyi*, Meek. This species was first described from the McCloud limestone, but has been found in eastern Russia near the top of C_2 in such large numbers as to give name to the zone.

Artinsk beds.—The argillites above the McCloud limestone are the equivalents of the Robinson beds of the Taylorsville region and of the Little Grizzly creek beds of Plumas county. These are probably homotaxial with the top of C_2, and the lower part of the Artinsk stage of Russia. They contain the following species closely related to forms of the Russian Artinsk stage, and the Productus limestone of the Salt Range in India:

Marginifera conf. *splendens*, Norwood and Pratten.
Productus conf. *cora*, d' Orbigny.
" conf. *scabriculus*, Martin.
" conf. *spiralis*, Waagen.
" group of *P., abichi*, Waagen.
Streptorhynchus conf. *pelargonatus*, Schlotheim.
Camarophoria conf. *purdoni*, Davidson.
Dielasma elongata, Schlotheim.
Spirifer interplicatus, Rothpletz.
S. (*Reticularia*) *lineatus*, Martin.
S. wynnei, Waagen.

In addition to some of these, the Robinson horizon of Plumas county contains a very long slender *Fusulina* that agrees closely with *F. longissima*, Möller from the Salt Range.

Of the above mentioned species *Marginifera* conf. *splendens* is the form usually identified with *Productus longispinus*, Sowerby in the Western Upper Carboniferous. *Productus* conf. *spiralis* is only a mutation of *P. semireticulatus*, Martin; *Spirifer wynnei* is a modification of *S. striatus*. Thus this fauna stands to the Carboniferous forms as mutations, showing only a slight difference in

age. It appears quite probable that they belong to the Artinsk stage, but it is also quite possible that they are homotaxial with the uppermost Coal Measures, because at the top of C_2 of the Russian Coal Measures many Permian species appear.

The inhabitants of the Eurasian and the North American Carboniferous seas belong to one type, the northern of Waagen,[1] and were separated from the southern regions.

POST-PALÆOZOIC REVOLUTION.[2]

Towards the end of the Carboniferous the greater part of the North American continent was raised above water; this revolution, or revolutions nearly contemporaneous with it, was very widespread, so that the break between the Palæozoic and Mesozoic has never been bridged over. Quite recently, however, Professor W. Waagen[3] has described from northwest India a set of fossils younger than the latest Permian and older than the oldest known Trias. But even here these forms are continuous with the Trias, but separated from the Permian by a break in life. In the West, therefore, the Triassic species are not descendants of the preceding local Palæozoic forms, but are foreigners, brought in by migration from regions as yet unknown. This itself, if we had no other proof, would be sufficient evidence that there must have been great stretches of continental margin where these faunas could develop, and that these breeding grounds have been mostly obliterated by the sea, so that we find their remnants in only a few places, such as the Salt Range in India.

TRIASSIC FAUNAS.

Lower Trias.—Even if we do not know where to look for the ancestors of the Triassic animals, we know well where to look for their contemporary kinsfolk. In California as yet no Lower Triassic fossils have been described, but rocks are here that are probably of that age, so that the finding of fossils is only a question of time.

[1] Salt Range Fossils, Geol. Results, p. 239.

[2] See TSCHERNYSCHEW, Mem. Com. Geol. Russie, Vol. III., No. 4, p. 364.

[3] Jahrbuch. K. K. Geol. Reichsanstalt Wien, 1892, Vol. XLII., Vorläufige Mittheilung ueber die Ablagerungen der Trias in der Salt Range.

But near by, in southeastern Idaho, are found Lower Triassic[1] fossils, of which the most characteristic are *Meekoceras gracilitatis*, White, *M. mushbachianum*, White, and *Xenodiscus aplanatus*, White. Very closely related forms have been described from the Salt Range of India by Waagen,[2] and from northern Siberia by Mojsisovics,[3] and from the Himalayas by Griesbach.[4] It is clear then that the post-Palæozoic revolution had not cut off the West Coast region from direct connection with the Indian and Arctic provinces. But these two provinces were probably cut off from the Mediterranean province, since it has been shown by Mojsisovics[5] that during Lower Triassic time *Tirolitinæ* were common, *Dinaritinæ* rare, but *Meekocerata* almost unknown in the Mediterranean region; while in the Arctic province there were no *Tirolitinæ*, but many *Dinaritinæ* and *Meekocerata*. Also Waagen[6] has recently shown that the same thing is true of the Salt Range and Himalayan Lower Triassic faunas.

The Idaho beds were, therefore, deposited on the extreme eastern border of a sea that stretched from the Salt Range eastward to America, and northwards to Siberia. And for the Lower Trias alone the Arctic-Pacific Trias province of Mojsisovics will hold good. In this province somewhere we have to seek for the ancestors of the *Ceratitidæ*, which Mojsisovics[7] says will be found among some of the *Meekocerata*, while Karpinsky[8] thinks it probable that the *Meekocerata* descended from the goniatite stock *Prolecanitidæ*.

Middle Trias.—Rocks of the Muschelkalk series are only doubtfully known in California, but a comparatively rich fauna of this age has been described from the Star Peak range in

[1] C. A. WHITE: Twelfth An. Rep. U. S. Geol. Surv. Terr., Part I., pp. 105–118.

[2] Pal. Indica, Salt Range Fossils, I. Productus Limestone Fossils, Cephalopoda.

[3] Mém. Acad. Impér. Sci. St. Pétersbourg, Series VII., Tome XXXVI., No. 5. Arktische Triasfaunen.

[4] Records Geol. Surv. India, Volume XIII. Part I., 1880.

[5] Arktische Triasfaunen, p. 149.

[6] Jahrb. K. K. Geol. Reichsanstalt Wien, Vol. XLII., 1892, pp. 384–5.

[7] Abhandl. K. K. Reichsanstalt Wien, Vol. VI., Part II., Cephal. Hallst. Kalke II. Part, p. 7.

[8] Ammoneen der Artinsk-Stufe, p. 43.

Nevada, by F. B. Meek.[1] This fauna has been shown by Mojsisovics[2] to possess certain elements unknown to the Arctic Lower and Middle Trias; these are *Trachyceras*, *Acrochordiceras*, *Eutomoceras*, *Arcestes*, and *Orthoceras*. But of these *Acrochordiceras*, *Arcestes* and *Orthoceras* are present in the Muschelkalk of the Mediterranean Trias province. *Trachyceras* is the culmination of the stock of *Tirolitinæ*, which according to Mojsisovics are wholly lacking in the Arctic Lower and Middle Trias, but are common in the Mediterranean province; to the latter region, then, we must look for the derivation of the Western *Trachycerata*.

Eutomoceras is a member of the *Tropitidæ*, which are unknown in the Mediterranean province during Middle Trias; their remote relative, *Sibirites*, is common in the Lower Trias of Siberia, and may have been an ancestral stock of the *Tropitidæ*, whose more remote progenitors, according to Mojsisovics,[3] are probably to be found among the *Gastriocerata*, which group is not uncommon in the American Upper Carboniferous.

We see, then, among the Western Middle Trias forms a considerable infusion of Mediterranean elements, showing that intermigration between the two regions has begun, but that intimate connection with the Arctic province still exists.

Upper Trias.—In California rich faunas of the Upper Trias have been described from Plumas county by W. M. Gabb[4] and Professor A. Hyatt,[5] and from Shasta county by the writer.[6] These faunas show an intimate connection with the Himalayan and Mediterranean provinces, but only a few species in common with the Upper Trias described from British Columbia by J. F. Whiteaves.[7]

The Upper Trias, Noric and Karnic, of Plumas and Shasta counties has yielded the following species thought to be

[1] Geol. Exploration Fortieth Parallel, Vol. IV.

[2] Arktische Triasfaunen, p. 148.

[3] Abhandl. K. K. Geol. Reichsanstalt Wien, Vol. VI., Part II., second half, p. 7.

[4] Palæont. Calif., Vol. I.

[5] Bull. Geol. Soc. Am., Vol. III., pp. 395–412.

[6] Jour. Geol., Vol. II., No. 6. Metamorphic Series Shasta County.

[7] Geol. Survey Canada. Contrib. Canad. Pal., Vol. I., Part II., pp. 127–149.

identical with, or nearly related to, forms described from the Tyrolean Alps:

Eutomoceras sandlingense, Hauer.
Isculites conf. *obolinus*, Dittmar.
Juvavites Group of *J. ehrlichi*, Mojsisovics.
Sagenites conf. *herbichi*, Mojsisovics.
Tropites conf. *dittmari*, Mojsisovics.
" aff. *marii*, Mojsisovics.
" conf. *sellai*, Mojsisovics.
" *subbullatus*, Hauer.
" *torquillus*, Mojsisovics.
Badiotites aff. *eryx*, Mojsisovics.
Polycyclus henseli, Oppel.
Trachyceras conf. *aon*, Muenster.
" aff. *archelaus*, Laube.
Tirolites (*Metatirolites*) *foliaceus*, Dittmar.
Nannites conf. *spurius*, Muenster.
Nautilus triadicus, Mojsisovics.
Halobia lommeli, Wissmann.
" conf. *rugosa*, Mojsisovics.
" *superba*, Mojsisovics.
Monotis salinaria, Schlotheim.

Many of these species also occur in the Himalayas, although until the completion of Mojsisovics' monograph on the Himalayan Upper Trias no exact comparison with that region is possible.

The above list shows that in California, as in the Himalayan and the Mediterranean provinces, with the beginning of the Karnic stage of the Upper Trias there came in from some unknown region a swarm of *Tropitidæ*. It is interesting to note that during this period the Salt Range fauna seems to have preserved its Arctic character, and to have been cut off from the sea in which the faunas of the Mediterranean, the Himalayan and the Californian provinces lived.[1] Again here we see an indication of a great change in physical geography, that has left no other record than the incursion of an exotic fauna.

JURASSIC FAUNAS.

Lias.—A marked hiatus separates the Lias of California from the Trias, as is the case everywhere else; the *Tropitidæ* and

[1] W. WAAGEN: Jahrb. K. K. Geol. Reichsanstalt Wien, Vol. XLII, 1892, p. 385.

Ceratitidæ have died out, and again a new fauna comes in from unknown regions. The lower Lias of California and Nevada, according to Professor A. Hyatt,[1] is characterized by the presence of *Arietidæ* of European habitus although not identical with European species.

The Lias[2] is typically developed over western Europe, and as far to the southeast as the Caucasus Mountains, but wholly unknown in eastern Europe, eastern Africa and continental Asia.

In the work cited, Neumayr has shown from the distribution of fossils and sediments during the Lias that then eastern Europe, nearly all Africa and Asia were above water, since Jurassic land-plants are found over much of this area; but on Japan is found Lias of European type.

Dr. O. Behrendsen[3] has recently described from the Argentine Republic lower Lias, with typical European species of *Arietidæ* and *Amaltheidæ*. The same type of Lias, with *Arietites geometricus*, Oppel, and *A. longicellus*, Quenstedt, has been described by Dr. A. Rothpletz[4] from Timor in the Indian Ocean. These species could not have migrated to or from Europe by the western way, since this was blocked by the continental mass at the junction of Europe, Asia and Africa. They along with the American species could only have migrated by the eastern way through the "Central Mediterranean Sea."[5] In this way we have in the Lower Jura of California a central European type of fauna.

Middle Jura.—The fossils of the Californian Middle Jura are too little known for us to be able to speak with certainty about their faunal relations, but the few species that have been described by Professor A. Hyatt[6] are probably of central European type.

[1] Bull. Geol. Soc. Am., Vol. V. Trias and Jura in the Western States.

[2] M. NEUMAYR: Denkschr. K. Akad. Wiss. Wien., Vol. L, 1885, Geograph. Verbreitung der Juraformation.

[3] Zeitschr. Deutsch. Geol. Gesell., 1891, p. 371.

[4] Palæontographica, Vol. XXXIX., p. 97.

[5] M. NEUMAYR: Geographische Verbreitung der Juraformation.

[6] Bull. Geol. Soc. Am., Vol. III., pp. 395–412.

Upper Jura.—The Upper Jura of California has been described from Plumas county and from the Mariposa formation of the Gold Belt by F. B. Meek in Vol. I. of the "Palæontology of California;" by Professor Hyatt,[1] and by the writer.[2]

The fossils described by Professor Hyatt from the Callovian and Corallian of Plumas county are of rather indecisive character, but seem to have their nearest affinities with central European species. This makes it probable that throughout the Callovian and part of the Oxford these waters were still connected with the central European. But at this same time there existed in the region of the Black Hills of Dakota and the Rocky Mountains a basin that contained a different fauna, and according to Professor Hyatt[3] was separated from the Californian basin. This central basin contains what Neumayr[4] has shown to be a decidedly Boreal fauna. In the paper referred to, Neumayr divided the Jura of the northern hemisphere in three distinct types, equatorial, temperate and Arctic. The Arctic or northern type occurs chiefly in Russia, and is characterized by the prevalence of *Cardioceras* and *Aucella*, and the absence of reef-building corals. Neumayr[5] has shown that the Black Hills Jura is a southern extension or bay of the Arctic sea.

It therefore becomes probable that during Oxford times the California area was still connected directly with the central European waters by way of the "Central Mediterranean Sea," and that the Black Hills basin was cut off from this, but connected with the Boreal sea of Russia.

Transgression of Upper Malm.—It has long been known that in Europe in the Middle Jura the sea began to transgress eastwards over the land until in the Upper Jura or Malm all eastern Europe and nearly all Asia were under water. This has been described by Neumayr[6] as one of the most striking events in

[1] Bull. Geol. Soc. Am., Vol. III., pp. 395–412; and Vol. V., pp. 395–434.

[2] Bull. Geol. Soc. Am., Vol. V., "Age of the Auriferous Slates of the Sierra Nevada."

[3] Bull. Geol. Soc. Am., Vol. III., p. 410.

[4] Denkschr. K. Akad. Wiss. Wien., 1883, pp. 301–302.

[5] Loc. cit.

[6] Geographische Verbreitung Juraformation, pp. 126–129.

geologic history, and one extending all over the northern hemisphere. But it becomes probable that while Eurasia was sinking, North America was rising, and that the eastward connection with European waters was cut off, for with the Kimmeridge there came in a fauna that no longer had any affinities with the central European, but rather with the Russian. This fauna has been described in the above mentioned papers by F. B. Meek, Professor A. Hyatt and the writer, from the Mariposa formation of the Gold Belt of California, also by Professor Nikitin[1] from San Luis Potosi in Mexico.

This type is characterized by the presence of *Cardioceras* of the group *C. alternans* and *Aucella* allied to *A. pallasi* and *A. bronni*.

There was, therefore, an elevation of a large part of America and also a transgression of the Boreal or Russian sea along the west coast as far as Mexico. This movement was correlative with the great Jura transgression of Eurasia.

It is a remarkable fact that this same fauna is found in the Spiti shales on the north side of the Himalaya Mountains while the Upper Jura of Kutch on the south side is of decidedly central European character. Neumayr[2] considers the Himalayan Jura a southward prolongation of the Boreal sea and the Kutch formation a prolongation of the central Mediterranean which also sent down a long gulf to Mombassa on the east coast of Africa. These African and Indian waters were separated from the western American by the ancient Australo-Asian continent, over which no marine Jura occurred, but widespread fresh-water deposits with Jurassic plants. Remains of this continent are still seen in Australia, New Zealand, and the submarine plateau on which are the islands that separate the Pacific from the Indian Ocean.

During all this time the Upper Jura of South America, as described by Dr. O. Behrendsen,[3] retained its central European

[1] Neues Jahrb. Min. Geol. und Pal., Band 2, 1890, p. 273.

[2] Geographische Verbreitung der Juraformation, pp. 109–117.

[3] Zeitschr. Deutsch. Geol. Gesell., 1891, pp. 369–420, and 1892, pp. 1–42.

character, having many species in common with that region, but being entirely cut off from the Californian.

CRETACEOUS FAUNAS.

Knoxville.—At the beginning of the Lower Cretaceous of California, as in the Upper Jura, we find that the closest affinities with foreign faunas are with the Volga stage of Russia. These beds and their faunas have been described by W. M. Gabb in the Palæontology of California, by J. S. Diller and T. W. Stanton,[1] and a similar fauna has been described from Queen Charlotte Islands by J. F. Whiteaves.[2] In the papers cited it has been shown that of the Knoxville fauna the following species are nearly related to Russian forms: *Aucella piochi*, Gabb, very near *A. mosquensis*, Buch; *A. crassicollis*, Keyserling, probably identical with the Russian species; *A. piochi*, var. *ovata*, possibly identical with *A. terebratuloides*, Lahusen; *Olcostephanus* aff. *discofalcatus*, Lahusen. And besides these there occurs *Hoplites* aff. *ambligonius* N. and U. These are sufficient to show a close faunal connection with Russian waters.

In addition to the species mentioned there are others of a Tithionan aspect, so that we have certainly the lowest Cretaceous and possibly the top of the Jura. Mr. Diller, in his various papers, has shown that the lowest Knoxville beds are separated from the highest Jura by a decided unconformity, but this does not represent any long time interval, and is not accompanied by any great change in life. The faunal geography was the same as at the close of the Mariposa epoch, and no new elements had come in; the change was due to development and intermigration between this region and Russia. Rocks of this age are unknown in India, so of the relation with southern Asia nothing can be said.

Horsetown.—In the Horsetown, or Gault, fauna it is seen that a great change has taken place; these beds lie conformably on the Knoxville, yet the Russian elements have nearly all died out,

[1] Bull. Geol. Soc. Am., Vol. IV., pp. 205–224; Vol. IV., pp. 245–256; Vol. V., pp. 435–464.

[2] Geol. Survey Canada, Mesozoic Fossils, Vol. I., Parts I. and III.

and a new fauna has come in, of which the majority could not have developed out of Knoxville forms, but are of southern type. This fauna is found in southern India, where it has been described by Stoliczka in the Palæontologia Indica.

The Horsetown[1] beds of California have yielded the following species thought to be identical with species from the Ootatoor group (Gault) of southern India:

Lytoceras sacya, Forbes.
Schloenbachia inflata, Sowerby.
Haploceras beudanti, Brongniart.

Besides these *Acanthoceras mamillare*, Schlotheim, unknown in India, is also found in the Horsetown.

The lower beds of Queen Charlotte Islands have yielded the above Indian species, and in addition to them several others as yet unknown in California. These species are nearly all also found in the Gault, Lower Cretaceous, of central Europe.[2]

Thus the Californian fauna has lost entirely its Boreal aspect since there was no longer any connection with Russia; rocks of this age are little known in that part of Europe.

Upper Cretaceous — Chico. — It has been shown by J. S. Diller and T. W. Stanton, in the papers cited above, that the Chico rocks and the Chico fauna are simply a continuation of the Horsetown. No Chico species are referred to European or Indian species, but many have near relatives in those regions. But the connection was still kept up, for the Upper Cretaceous of Vancouver Island still shows the presence of Indian types. On the other hand there seems to have been little connection with the interior region.

During the Cretaceous there was a revolution in the West, for in California the uppermost Cretaceous and the lowest Eocene are lacking. But we do not know how extensive this was, since

[1] See the papers of J. F. Whiteaves, J. S. Diller and T. W. Stanton cited above.

[2] A paper by Mr. F. M. Anderson on Some Cretaceous beds of Rogue River Valley, Oregon (this number Journal Geology), materially increases the list of Indian species on the West Coast, but all the facts stated about the Cretaceous were taken wholly from previously published works on the subject.

the Eocene of Asia is too little known for any comparison with the California Eocene to have value.

The distribution of Upper Cretaceous fossils on the West Coast seems to conform to the climatic zones[1] as they existed in Africa and Europe, California and British Columbia having the central European type, while Lower California and Mexico have the equatorial type with *Hippurites* and *Buchiceras*.

After the Cretaceous, and indeed before the end of it, the faunas seem to have been limited closely to their present ranges.

SUMMARY.

From the foregoing pages the following conclusions are reached:

At the beginning of the Upper Devonian some widespread disturbance occurred, opening up connection between the American and Eurasian seas.

The Lower Carboniferous fauna of California was developed directly out of Devonian predecessors with the addition of some Eurasian elements by migration.

The Upper Carboniferous fauna was developed out of that of the Lower Carboniferous, but still with intermigration with the Russian and Asiatic regions, so that the California Carboniferous resembles the Eurasian even more than it does that of the eastern United States.

The Lower Triassic fauna of the West is entirely foreign, having migrated in from unknown regions, but having reached nearly simultaneously the western part of America, the Salt Range in India, and northern Siberia, but having been cut off from central Europe.

The Middle Trias of the West already begins to show relationships to the Mediterranean province of Europe, showing a connection in that direction, while the similarity to the faunas of the Arctic Trias province is disappearing.

In the Upper Trias the nearest faunal affinities are with the Himalayan and the Mediterranean provinces.

[1] M. NEUMAYR: Klimatische Zonen während Jura und Kreide Zeit.

In the Lower and Middle Jura there was no connection with European waters through the Pacific region, but rather through the Atlantic or "Central Mediterranean Sea" of Neumayr, bringing a central European fauna.

Near the beginning of the Upper Jura this connection with European waters was cut off, and one established with those of Siberia and northern Europe, bringing in a Boreal fauna.

This same connection was continued through part of the Lower Cretaceous, giving a Boreal fauna to the Knoxville.

Near the beginning of the Gault, connection with the Boreal sea of Russia was cut off, and communication established with southern India and through that country with central and southern Europe, bringing in a warm-water fauna. This connection existed during the greater part of the Cretaceous, but after this time the faunas are confined much more closely to their present ranges, although even today many of our living and Tertiary mollusca are found in Japan.

These changes in faunal geography are too widespread and easily correlated over great areas to be charged to mere mountain-making; they must rather be of the nature of continental uplift and subsidence. A study of these changes will throw light on the problem of the extinction of faunas and explain the great poverty of certain beds, in which the conditions for life seem favorable.

The fauna of California has not been a genetic series, but rather a succession of independent faunas, derived by migration from various parts of the earth, complicated by the mixture with the products of local development. Therefore the student that would intelligently study the genesis and history of this fauna must not neglect the fossil records of any region, since all may have contributed some elements to this complex assemblage of forms.

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THE AGE AND SUCCESSION OF THE IGNEOUS ROCKS OF THE SIERRA NEVADA.[1]

THE following notes and suggestions on the age of the igneous rocks of the Sierra Nevada are the outgrowth of field work in two parts of the range; one portion being a strip thirty miles wide across the mountains just south of the fortieth parallel, chiefly in the area of the Chico, Bidwell Bar and Downieville sheets of the United States Geological Survey; the other portion that part of the range to the south of Cosumnes River, or approximately latitude 38° 30′ N. The succession has been made out only partially and for only certain districts, and the article should therefore be considered merely as a contribution to the subject which must be later revised, and can be fully treated of only after more field work and a more thorough study of the material now on hand.

Mr. Waldemar Lindgren has acquired a large amount of information concerning the district across the central part of the range from Sacramento to Lake Tahoe, the geological maps of which have been prepared under his direction, and much light may be expected when his results are published. The writer is indebted to Mr. Lindgren for friendly criticisms.

The Sierra Nevada as a topographic unit may be described, following Whitney,[2] as the mountain area lying to the east of the Great Valley of California and to the west of the Great Basin, extending from near the Tejon Pass at the south end of the Great Valley to Lassen Peak on the north. As thus defined, the

[1] Published by permission of the Director of the U. S. Geological survey.

The chemical analyses given in this paper, unless otherwise stated, have been made by Dr. W. F. Hillebrand of the U. S. Geological Survey, whose high standing as an analyst is well known.

[2] Auriferous Gravels of the Sierra Nevada, p. 7.

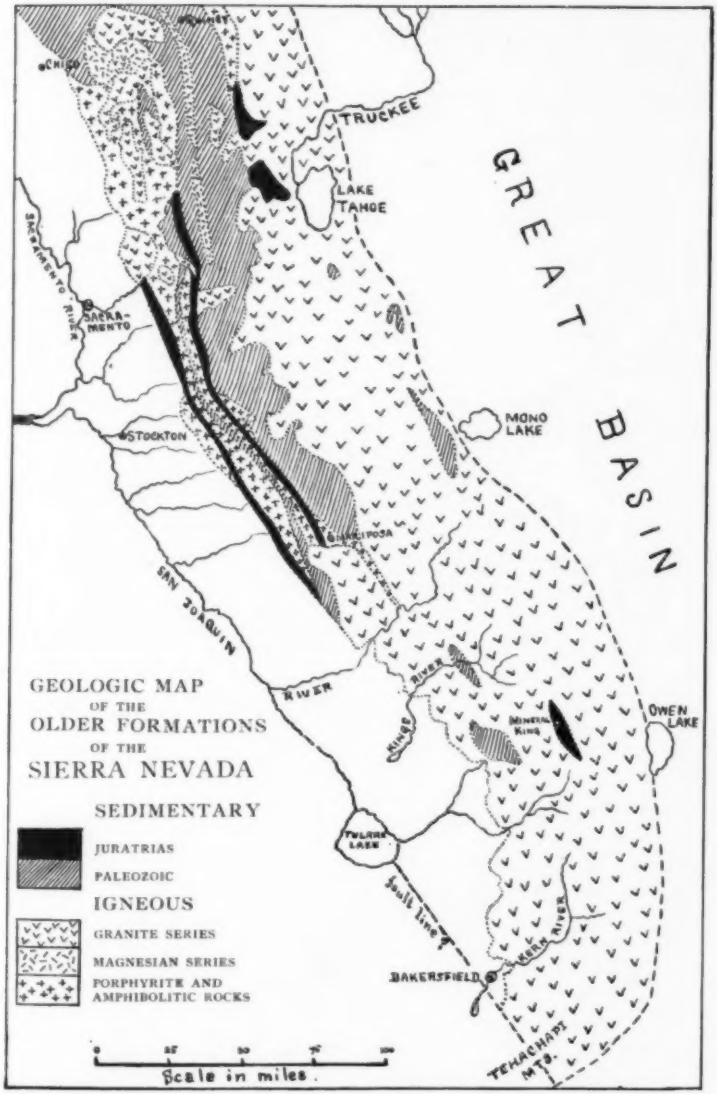
range lies wholly in the state of California, except the high granite spur lying just east of Lake Tahoe. Diller[1] has suggested, however, on geological grounds, that the range be limited on the north by the lavas of the Lassen Peak region, in the neighborhood of the North Fork of the Feather River, for to the north of this line there existed during Cretaceous time a great depression, which late in the Tertiary was filled in by the lava flows of Lassen Peak, which Diller considers as geologically related to the Cascade Range.

A little to the west of the Tejon Pass, according to Whitney,[2] "we pass at once from undisturbed Tertiary to strata of the same age, which are elevated at a high angle, and in so doing we leave the system of the Sierra and pass to that of the Coast Ranges." In a previous paper[3] the writer suggested that this line, separating little disturbed and highly disturbed beds, probably represents a line of faulting, the continuation of which further north is apparently followed by the San Joaquin and Sacramento Rivers. As is well known, the upper Cretaceous and Tertiary strata to the east of these rivers in the Sierra Nevada lie nearly horizontal, while to the west of it they are at nearly all points deformed. Adopting Diller's restriction of the range at its north end, the Sierra Nevada may be considered as terminating on the north, a little to the north of the North Fork of the Feather River; on the east at the west edge of the Great Basin; on the south at the Mojave Desert; and on the west at the hypothetical line of faulting above indicated. The eastern part of the Tehachapi Mountains will thus fall in the Sierra Nevada system. The geologic map (Plate VII) shows the range as thus restricted, the broken lines on the east and south being the line separating the Sierra Nevada from the Great Basin and the Mojave Desert. That portion of this line between Owen and Mono Lakes, and the portion east of Lake Tahoe coincide with a probable line of faulting, along which the Sierra has been elevated or the Great

[1] Eighth Annual Report, U. S. Geol. Surv., p. 404 and Plate XLV.

[2] Geol. Cal., Vol. I., p. 167.

[3] American Geologist, Vol. XIII., p. 248.


CHICO
TRUCKEE
LAKE TAHOE
GREAT BASIN
SACRAMENTO RIVER
SACRAMENTO
STOCKTON
MONO LAKE
MARIPOSA
SAN JOAQUIN RIVER
KINGS RIVER
OWEN LAKE
TULARE LAKE
SOUTH FORK
KERN RIVER
BAKERSFIELD
TEHACHAPI MTS.
GEOLOGIC MAP
OF THE
OLDER FORMATIONS
OF THE
SIERRA NEVADA
SEDIMENTARY
JURATRIAS
PALEOZOIC
IGNEOUS
GRANITE SERIES
MAGNESIAN SERIES
PORPHYRITE AND
AMPHIBOLITIC ROCKS
Scale in miles.

Basin depressed (or perhaps movements in both directions have occurred) in Tertiary time.

The Sierra Nevada, as thus outlined, appears to constitute a block of the earth's crust that has been practically rigid since middle Cretaceous time, although it has since, in common with most of California, experienced a considerable elevation, and there has been displacement by normal faults within the mass, particularly in Plumas county, at the north end of the range.

In another respect also the Sierra may be considered a geologic unit. The Tertiary lavas throughout the mass that have the widest distribution are very similar at distant points, and unlike Tertiary lavas in other adjacent areas, especially as to their form of occurrence and their relation in time. Thus the oldest flows of large extent were of rhyolite, succeeded by hornblende-pyroxene-andesite, chiefly in the form of tuff and breccia. This relation does not appear to hold good in the Lassen Peak region or in the Great Basin. The sediments of which the Sierra Nevada are in part composed are presumed to have been derived chiefly from an Archean land mass lying west of the central part of the state of Nevada, although it is by no means impossible that an Archean land area once existed on the site of the present Coast Range, and in that case part of the sediments may have been derived from the West. It is probable that there are within the Sierra Nevada formations ranging in age from Archean or Algonkian to Recent. Excepting, however, some Silurian fossils at the north end of the range, no evidence has thus far been found of rocks older than the Carboniferous, although in the northwest extension of the Auriferous Slate series of the Sierra Nevada in Siskiyou and Shasta counties, Diller and Fairbanks have collected Devonian fossils. On the geologic map (Plate VII.) only the older formations, constituting the Auriferous Slate series with the associated igneous rocks, are represented. On this map the Palæozoic corresponds with the Calaveras formation of the Gold Belt maps; the two narrow belts of Jura-Trias, on the west slope of the range, are the Mariposa beds; the Jura-Trias beds northwest of Lake Tahoe are the Sailor-Canyon and

Milton series, and the area in the southern part of the Sierra at Mineral King is probably Triassic in age. Under granite, which forms much the larger part of the range, are included the potash-poor granite or granodiorite of Becker, or tonalite of Vom Rath, and the porphyritic granite,[1] described in the Fourteenth Annual Report, United States Geological Survey. Nearly all the small areas noted on the map enclosed in schists or in basic igneous rocks are granodiorite, the porphyritic granite occurring chiefly along the crest of the range, especially in its southern part. The Magnesian series comprises serpentine, talc and tremolite schists with some other associated amphibolitic schists, the entire series being derived from basic igneous rocks. The porphyrites and amphibolitic rocks comprise the rocks laid down on the Gold Belt maps as diabase and porphyrite and amphibolite-schist derived therefrom, and altered igneous rocks which are now diorites, and which may be designated, following Cross, metadiorites, that is to say, diorites formed from other rocks by metamorphism without reference to the character of the original rocks. The material first determined by Wadsworth[2] as diabase-tufa forms a part of this series. There is, however, very little true diabase in the range, while porphyrites (altered andesites) on the other hand are abundant. The bisilicate that is most common in the porphyrite is augite, but large masses contain augite in very subordinate amount. Certain very basic portions of these areas seem to have contained olivine and are probably melaphyres. The silica contents of the series ranges from 48.86 per cent. in the melaphyre-like rocks to 68.56 per cent. in the porphyrites with metasilicates in small amount, and in some areas the acid porphyries grade over into still more acid varieties containing free quartz, as in the rocks of the Gopher Ridge. (See Jackson geologic folio.) The amphibolitic schists included within the porphyrite and amphibolite areas were

[1] This porphyritic granite was wrongly designated a granite-porphyry in the Fourteenth Annual Report, U. S. Geological Survey and in the American Geologist, Vol. XIII., p. 305. A similar use of the term may however be found in Hatch's Petrology, 1892, p. 114.

[2] Auriferous Gravels, p. 44.

formed from the porphyrites, melaphyres, etc., by dynamo-metamorphism. So generally have all these rocks been compressed that few outcrops can be found which do not show a rough schistosity. Let us add that the structure of these porphyrites and melaphyres is so obscured by secondary minerals (uralite, epidote, chlorite, zoisite and calcite) that it is little to be wondered that their true nature has not been clearly understood. It is now plain that the chief part of the rocks laid down on the geologic map as porphyrite and amphibolite schist are altered forms of original surface lavas and tuffs corresponding to modern basalts and andesites.

As has been stated before, the oldest known rocks in the Sierra Nevada, south of the fortieth parallel, are of Carboniferous age, and in treating of the history of the volcanic phenomena of the range we will commence with that period.

In the foothills of Eldorado, Amador, and Calaveras counties (see Placerville and Jackson folios) there is a narrow belt of clay-slate in which are numerous limestone croppings, and in several of these Carboniferous fossils have been found. Interbedded with the slate and limestone at several points are layers of conglomerate, composed of well-rounded pebbles. One of these layers is exposed by the road to Plymouth, in Amador county, northwest of Sugar Loaf, and at other points, and there is another similar one (possibly the same horizon) about three miles northwest of Golden Gate Mountain in Calaveras county. It is to be presumed that these conglomerates are of the age of the enclosing rocks, and in that case the pebbles they contain indicate with certainty the kind of rocks that existed before the Carboniferous or during an earlier portion of that period. The pebbles are largely of igneous rocks, although quartzite pebbles are present. The igneous pebbles are chiefly hornblende and mica porphyrites, but holocrystalline rocks, with idiomorphic augite, plagioclase, and leucoxene enclosed in orthoclase are also represented. The leucoxene appears to have formed from ilmenite. The plagioclase is mostly decomposed, as is also part of the augite. The orthoclase is largely fresh. The last-men-

tioned pebbles may be called augite-syenite. A partial analysis of one of them (No. 30 Amador county) by Dr. Stokes of the United States Geological Survey, gave the following results:

	No. 30 Amador.	165 S. N.
SiO_2	55.45	55.04
MgO	4.11	3.41
K_2O	5.18	1.41
Na_2O	1.73	4.27

A rock in place closely resembling these pebbles has been found near Nevada City, by W. Lindgren, and is shown on his Grass Valley sheet in the Nevada City folio. To the north of Tehuantepec Valley in the area of the Downieville atlas sheet is a large mass of granitoid rock that has very nearly the same mineral composition and structure as the pebble above described. An analysis by Dr. Stokes of a specimen from this area is given above (No. 165 S. N.). This rock is composed of plagioclase, augite, rhombic pyroxene, iron ore, and brown mica enclosed in later unstriated feldspar that appears to be orthoclase, although the chemical analysis does not show enough potassa for much orthoclase to be present. The augite is plainly later than the plagioclases in places indicating a tendency to ophitic structure. There is a little quartz in the rock. All the constituents are fresh.

In the area of the Placerville sheet in southern Eldorado county, in the same belt of Carboniferous rocks noted above as containing conglomerate, there are numerous areas of igneous material. One of these, forming the hill known as Big Sugar Loaf, is a boss of porphyrite containing quartz and hornblende phenocrysts, and extending from this mass north across Slate Creek is a narrow dike containing abundant primary brown hornblende needles. This porphyrite boss is believed to represent an eruption of Carboniferous time. About three and a half miles north of Big Sugar Loaf is a hornblende-porphyrite area, and thin sections of the rock show a devitrified groundmass exhibiting flow structure. It is possible, however, to regard these masses as intrusive and younger than the enclosing slates, but

other elongated areas called diabase and porphyrite (db), on the Placerville map in the vicinity of these hornblende-porphyrite areas, are distinct tuffs and volcanic agglomerates, and there can be no reasonable doubt that the igneous fragments they contain were derived from volcanoes existing at the time the beds were forming. As hornblendic and augitic porphyrite fragments are very common in the agglomerates, we may safely assume that eruptions of porphyrite (old andesite) took place in the Carboniferous time in the foothill region. Exactly similar evidence is presented in the same belt of Carboniferous rocks in the area of the Jackson sheet. There are numerous streaks of fragmental porphyrites that are interbedded with the slates and evidently contemporaneous with them. In mapping these fragmental areas, the writer in places found much difficulty in deciding whether to lay down certain masses as pyroclastic rocks or as ordinary sediments, for there is a gradation from one to the other in places. The rule followed was to regard those layers as igneous that were chiefly composed of igneous fragments.

The most positive evidence of volcanic eruptions during the Carboniferous period has been brought forward by Diller,[1] who described a bed of tuff near Genesee Valley at the north end of the range in which Upper Carboniferous fossils were found. Mr. T. W. Stanton kindly collected a specimen of this tuff for the writer, on one side of which are shell impressions. A thin section shows numerous plagioclase phenocrysts and some non-twinned feldspars, probably orthoclase, in an altered groundmass containing very abundant minute fibers of a brightly polarizing secondary mineral, perhaps uralite. A partial analysis of this rock (No. 80 S. N.) made by Augustus Wedderburn under the direction of Professor Chas. E. Munroe, of the Columbian University, shows 5.01 per cent. of potassa, and 1.94 per cent. of soda. It is probably a trachyte.

The fossiliferous Upper Carboniferous beds on Little Grizzly Creek[2] are interbedded with porphyritic volcanic material more

[1] Bulletin Geological Society America, Vol. III., p. 374.

[2] American Geologist, Vol. XIII., p. 230, and Fourteenth Annual Report, U. S. Geological Survey, p. 448.

or less similar to that of the Robinson beds near Genesee Valley, but the rock in which the fossils occur is not itself a distinct tuff. It is composed of minute grains, probably of both quartz and feldspar, with abundant secondary greenish brown mica in minute irregular foils and green hornblende in slender fibers. The porphyritic feldspars in the tuff (No. 219, Plumas county) found just north of the Little Grizzly Creek fossil beds, and with little doubt part of the same series, appear to be largely orthoclase. Another similar tuff from an area farther south (No. 352) contains likewise large feldspars, some of them three-tenths of an inch in diameter. These are in part microcline. The same greenish brown mica found at the two other localities above described is also present in the groundmass. This and the greenish hornblende is probably the result of contact-metamorphism as granite occurs near each. A partial analysis by George Steiger, of No. 352, shows it to have approximately the composition of a trachyte.[1] Following the Carboniferous comes the Trias. Beds of this age have been found at Mineral King, at Genesee Valley and on Rush Creek. At the latter locality is a bed of conglomerate interstratified with slate and limestone, the latter containing pentagonal crinoid stems. This conglomerate was first discovered by J. E. Mills[2] and was visited by the writer in company with Mr. Diller. The pebbles of this conglomerate are well rounded, and may have been derived from land areas composed of Palæozoic rocks. Igneous pebbles are very abundant. These consist chiefly of quartz-diorites that seem originally to have been quartz-gabbros, the pyroxene now being hornblende. One pebble is chiefly made up of hornblende derived from pyroxene with a few spots of secondary material containing aggregates of minute, black particles, representing possibly original olivine, in which case this rock was a lherzolite. This pebble may have been derived from the large area now largely serpentine that forms Red Hill, just west of Rush Creek. Mr. Mills in his bulletin states that he found pebbles of granite like that forming Spanish Peak, but he

[1] Fourteenth Annual Report, U. S. Geological Survey, p. 448.

[2] Bulletin Geological Society, Vol. III., p. 429.

does not appear to have had the specimens examined microscopically. Neither Mr. Diller nor the writer found any pebbles of the Spanish Peak rock (a quartz-mica-diorite) in the conglomerate. The southern extension of the Red Hill serpentine area is shown on the geologic map a little west of Quincy.

The long belts of porphyrite and amphibolite indicated on the map on either side of the narrow belt of Palæozoic (in this case certainly Carboniferous) rocks are very probably Jura-Trias in age. In fact, certain portions are without doubt of Jurassic age. A section across the Bear Mountains, which lie east of Stockton, shows the relation of the igneous and sedimentary formations.

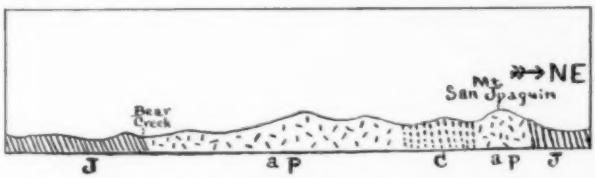


FIG. 1. Section across the Bear Mountains, extending vertically to sea-level. C.—Carboniferous slates. J.—Jurassic slates. ap.—Porphyrite, porphyrite tuffs, and amphibolite. Vertical and horizontal scale two miles to the inch.

We have here a central belt of Carboniferous slates flanked on either side by augitic porphyrites and tuffs, and at both the east and west base of the Bear Mountains are Jurassic slates, which have been designated the Mariposa formation. The porphyrites and their tuffs being surface formations, there seems good ground for regarding them as products of volcanoes that existed after the Carboniferous and before the close of the Jurassic. It may also be assumed that the portions of each porphyrite belt lying nearest the Carboniferous slates are the oldest. The tuffs along the east borders of the eastern area merge into the Jurassic slates, the latter containing frequent layers of the augite-tuff, so that it is difficult on the east slope of the Bear Mountains to draw an exact line between the tuff and the slates. There can be no doubt as to the age of these tuff layers, for in some of them ammonites have been found. The one found nearest the line of the section came from a branch of Cherokee Creek at the

east base of the Bear Mountains, and occurs in an augitic slate.[1] In the collection of Stanford University there are two specimens of ammonites from the same horizon as the Cherokee Creek specimen, although the localities are further north on the area of the Placerville sheet. The rock in which the fossils occur is a distinct augite-porphyrite tuff, and would ordinarily be called greenstone. The writer is indebted to Professor J. P. Smith for the following information concerning them: One ammonite is *Perisphinctes* conf. *colfaxi* Gabb sp., and was found by Mrs. M. J. Gates at Huse's bridge over the Cosumnes river; the other is *Perisphinctes* sp. or *Olcostephanus*, and was found in a bowlder near Nashville, Eldorado county, by J. C. Heald. Both species indicate the Upper Jura.

According to Diller,[2] the Hinchman tuff at Mt. Jura in Plumas county contains lapilli, affording evidence in that section of volcanoes during the time of deposition of the tuff (Upper Jura). Mt. Jura is perhaps one of the best places in the range for the chronological study of ancient volcanic materials, both on account of the greater freshness of the rocks and the abundance of fossils.

As will be noted on the geologic map, the large area of porphyrite and amphibolite widens going north. On the Smartsville geologic map, now being published, these rocks may be seen to occupy a large portion of the surface of the country. They have been studied mostly by Mr. W. Lindgren, who agrees with the writer in regarding them as chiefly surface eruptions and probably Jura-Trias in age. These rocks, largely augite-porphyrites and their tuffs, are presumed to have covered, as with a mantle, the underlying Palæozoic formations. There are some streaks of slates among the eruptive masses, but these have not in the Smartsville area afforded any fossils. However, during the past season, in the north extension of the same area, in a belt of clay-slate interbedded with augite-breccia and tuff, fossil plants were collected by T. W. Stanton. The exact locality is by the stage

[1] Fourteenth Annual Report U. S. Geological Survey, p. 453.

[2] Bull. Geol. Soc. Am., Vol. III., p. 373.

road south of the Oroville Table mountain, near the Banner gold quartz mine. Professor Ward examined these plant remains and expressed the opinion that they are of middle Mesozoic age, and then referred them to Professor Fontaine, whose report is herewith appended:

[*Extract from letter of Professor Wm. M. Fontaine to Professor Lester F. Ward, dated April 22, 1895.*]

I have examined carefully the plants from near Oroville, Cal., collected by Stanton and Oliver, with the following results:

1. Perhaps the most common form is a *Tæniopteris*, which I cannot distinguish from *T. stenoneura*, Schenk, found in the Grenzschichten and in the lower Rhetic of France.

2. Not uncommon is a narrow form which is most probably *Tæniopteris tenuinervis* of the same beds, and which is still more characteristic of the Rhetic.

These narrow Tæniopteris forms are the most abundant imprints among the California fossils. This type goes up, it is true, as far as the Oolite, but in species not seen among these fossils. Macrotæniopteris, if present, must be much rarer than Tæniopteris. I am not sure that any of this type is present. There is one large fragment, poorly preserved, that looks much like a Macrotæniopteris, which resembles *M. magnifolia*. There is a ribbed imprint, an imprint of the inner wall of either an Equisetum or Schizoneura. It looks more like the imprint Schenk calls *Calamites Gumbeli* of the Grensch, which Schimper makes *Equisetum Gumbeli*. There is a very fine plant of *Ctenophyllum grandifolium* of the Richmond coal field, and several fragments of the same plant. This is of great value in fixing the age of the strata, as this type of plant is unmistakable, and is not known except in the uppermost Trias and Rhetic. Schenk's *Pterophyllum carnallianum* is probably a small variety of it. I may say here that a few years ago some Mexican brought a few fossil plants from Mexico, and they were submitted to me. Among them were fine specimens of this Ctenophyllum, and from them I felt sure that uppermost Trias and Rhetic extend into Mexico.

There are several good imprints of a Podozamites which I cannot distinguish from *P. Emmonsi* of the N. C. uppermost Trias. Possibly it may be *P. lanceolatus*. If so, it is the Rhetic rather than the Jurassic type of this widely extended and persistent form of Podozamites. It is now so much expanded by species-makers that it is rather a group-type than a species, like *Pecopteris Whitbiensis*.

There are a number of scattered leaves like Schenk's *Zamites angustifolius* or more probably *Podozamites tenuistrictus* of the Richmond coal.

There is an imperfectly preserved imprint of a very large Danæopsis,

probably *Danæopsis marantacea*, another Rhetic plant. It shows the nervation and basal portion of several pinnules attached to the rachis.

There are probably three different ferns, but they are so few and in such small fragments of the terminal portions of ultimate pinnæ, that nothing of their true nature can be made out. It is impossible to say if they are Triassic or Jurassic. They have rather more of a Jurassic than a Triassic facies.

Taking all the evidence, I think it can be positively said that *this flora is not older than the uppermost Trias, and not younger than the Oolite.* I feel pretty sure that it is true Rhetic, somewhat younger than the Los Bronces flora of Newberry, and the Virginia Mesozoic coal strata. It is much like the Rhetic flora of France, made known by Saporta. At any rate, this *is a new grouping of plants that certainly deserves to be carefully collected. I do not think the fossils now in hand suffice to fix narrowly the age, which may be lower Jurassic.*

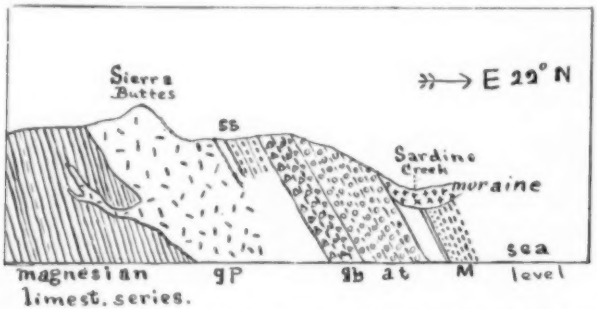


FIG. 2. Section across the Sierra Buttes. Horizontal and vertical scale one mile to the inch. qp=quartz-porphyry. qb=quartz-porphyry breccia. at=augitic tuffs. M=Milton series. ss=siliceous schist.

On the east slope of the Sierra Buttes (Downieville atlas sheet) the rocks are magnificently exposed through glacial agency, and during the past season the writer obtained evidence there of the succession (see Fig. 2) of the old volcanic rocks which form the larger part of the Buttes.

Forming the mass of the Buttes is a fine-grained rock containing abundant porphyritic quartzes. No analysis has been made of the Sierra Buttes rock, but from the north end of the same area, which extends to Eureka Peak, three specimens were collected and analyzed,[1] giving the following results:

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 473.

Silica	73.62 per cent.	to	79.41 per cent.
Lime	.09 "	"	2.55 " "
Potassa	2.23 "	"	4.27 " "
Soda	2.46 "	"	3.78 " "

As there is some carbonate in minute particles in these rocks, it is quite likely that in the fresh rock the lime never reaches as small a quantity as .09 per cent. Although containing too much lime and too little potassa for a typical quartz-porphyry, the variation is not sufficient to exclude the rock from the quartz-porphyry group, and it will be so called here.[1]

Overlying the quartz-porphyry is a sedimentary lens, partly a dark siliceous schist and partly coarser material, dipping easterly at angles of from 50° to 60°. In this lens is the quartz vein of the Mountain mine. At one point in the sedimentary mass is a layer of quartz-porphyry about 50 feet thick which may be an intruded sheet or a contemporaneous flow. Radiolarian-like remains were noted in the sections of a dark, fine-grained breccia that forms part of this clastic series. This sedimentary mass has been designated a "lens" since it feathers out both to the north and south. Other lenses, usually entirely made up of dark siliceous schist and slate, occur in the Sierra Buttes, from one of which at the Phœnix mine an ammonite was collected.[2] Some of these lenses are entirely enclosed in the quartz-porphyry, and it is probable that the entire series, the quartz-porphyry as well as the overlying formations, is Jura-Trias in age.

Superimposed with apparent conformity on the clastic series just described is a breccia containing abundant angular microlitic fragments and angular quartzes which are in part idiomorphic. This series is designated in the section a quartz-porphyry breccia, overlying which is a huge bed of altered augitic pyroclastic rock without free quartz. Moraine material covers the lower part of the slope, but one mile further south in the bed of the North Fork of the North Fork of the Yuba River, this augitic tuff is

[1] CROSS gives analyses of two quartz-porphyries from Leadville that contain very similar silica, lime and alkali ratios to those given above. Monograph XII., U. S. Geol. Survey, p. 326.

[2] Am. Geol., Vol. XIII., p. 232.

plainly seen to be conformably overlain by the red slates and fine-grained tuffs of the Milton series. Near Milton, there is good evidence that this last series is unconformable on the Palæozoic rocks to the west. These Palæozoic rocks are called in the section the magnesian-limestone series, there being in it frequent irregular masses of magnesian limestone, but no fossils have been found in any portion of it, and it is presumed to be Palæozoic in age on account of the highly metamorphosed condition of most of the material composing it. There are dikes of quartz-porphyry in the magnesian-limestone series. The dip of the pyroclastic and clastic rocks overlying the quartz-porphyry of the Sierra Buttes is to the east at angles varying from 50° to 60°. The dip of the Palæozoic rocks to the west is often vertical, but dips to the east at high angles have been noted at many points. While these dips represent in part the dip of the original stratification, at some points they probably indicate the dip of the schistosity.

To the east of the Milton series is a large granite mass which appears to be of later age, since the Milton rocks show evidence of contact metamorphism.

There are then at the Sierra Buttes an acid volcanic series (quartz-porphyry and quartz-porphyry-breccia), with an overlying augitic pyroclastic series more basic in composition, and later than the whole volcanic series, a deep-seated intrusive acid rock (granodiorite).

The succession of the effusive rocks, acid quartz-porphyries, and more basic augitic tuffs, is strikingly similar to the succession of the Tertiary effusives, rhyolites and andesites, described hereafter.

In addition to the above rocks, there are in the same region numerous dikes cutting the various igneous formations. Thus the quartz-porphyry of Eureka Peak (same area as that of the Sierra Buttes) is cut by dikes of an altered rock that appears to be an aplite (No. 150 Plumas), and also by a more basic rock, probably originally an augitic porphyrite (Nos. 385 and 386 Plumas), but the idiomorphic phenocrysts of this are now

fibrous hornblende. On the southwest slope of Mt. Elwell, the augitic tuffs that overlie the quartz-porphyry series are cut by a dike of a white rock (No. 108 Plumas) of a fine-grained granular structure, and composed of quartz and feldspar with smaller amounts of secondary epidote and fibrous hornblende. The rock is thought to be an aplite. The same augitic tuff series at a point about one and three-fourth miles southeast of Mt. Elwell is cut by a dike of hornblende-porphyrite (No. 206 Sierra county). Forming the east base of Eureka Peak is a dark, coarse, granular rock which is seen under the microscope to be a gabbro. The contact of this rock with the quartz-porphyry is sharp, and as there are angular fragments of the gabbro enclosed in the porphyry, it appears that the gabbro is the older rock. At a point eight-tenths of a mile (No. 133 Plumas), and at another point one and three-fourths miles southeast of Eureka Peak, there are in this gabbro white dikes that microscopically appear to be aplites. Cutting No. 135 is a darker colored dike (No. 136) which contains outlines of squarish crystals, one showing truncated corners, presumably originally augite (but now replaced by calcite, epidote, quartz and chlorite), in a microlitic feldspar groundmass. In a ravine on the northeast slope of Eureka Peak enclosed in the quartz-porphyry there are fragments of a rock weathering reddish (No. 383 Plumas). On microscopic examination these proved to be apparently quartz-diabase, identical in structure with the rock (No. 550 Calaveras) that occurs as a dike in the granitoid quartz-porphyry southeast of Milton near Rock Creek (Jackson atlas sheet). The rock is ophitic in structure, the divergent plagioclases penetrating the quartz grains as well as the chlorite and epidote which seem to represent original augite. In No. 550, the metasilicate is chiefly hornblende, which is presumed also to have been augite. In addition there are numerous grains of iron ore. This peculiar ophitic rock has thus far been noted by the writer only at the two points above mentioned. As the rock needs more investigation, it will not be further considered here.

Six and seven-tenths miles southeast of the Sierra Buttes in

he granite (granodiorite) is a dike of augite-porphyrite (No. 226 S. N.) in which the augite is largely altered to fibrous green hornblende which is grouped in radiating brushes. Some of the augites are unaltered at the center with a rim of the coarsely fibrous hornblende. If there was olivine in the rock, it is now completely gone. The rock is dark green in color, strongly resembling the rock that forms a small area on the summit of the highest of the Sierra Buttes, and this latter rock appears to have contained olivine and would then be a melaphyre. Along the augite-porphyrite dike (No. 226 S. N.) is a white dike (No. 227 S. N.) about two feet wide which thus occurs between the augite-porphyrite and the granite. This rock appears to be a micropegmatitic form of aplite. The time relation of the augite-porphyrite and the aplite was not ascertained.

Chemical analyses of the dikes have not been made, but if the writer is correct in his determination of these altered rocks, we have the following succession in the Eureka Peak–Sierra Buttes region.

MEDIUM BASIC	Gabbro — Boss.	
ACID	Quartz-porphyry — effusive, large sheet.	
MEDIUM BASIC	Augite porphyrite — effusive, mostly tuff, large sheet.	
ACID	Granite (granodiorite).	Intrusive.
ACID	Aplite.	
BASIC	Augite-porphyrite (?) or melaphyre (?)	
MEDIUM BASIC (?)	Hornblende-porphyrite.	

The relative age of the aplite, late augite-porphyrite, and hornblende-porphyrite yet remains in doubt, the only evidence being that the greenish dike (No. 136), apparently an augite-porphyrite, cuts the aplitic dike (No. 133).

In the area of the Jackson sheet are a number of bodies of rock that are designated on the geologic map of that area as quartz-porphyrite. Analyses[1] of these rocks, however, show them to have a composition very similar to the quartz-porphyry of the Sierra Buttes. The quartz-porphyrites should perhaps be restricted to altered andesitic rocks with free quartz, and with less than 70 per cent. of silica, corresponding to modern dacites.

[1] Fourteenth An. Rep. U. S. Geol. Survey, p. 484.

If this rule be followed, all of the quartz-porphyrites of the Jackson geologic map should be called quartz-porphyries. The following analyses, however, show that the lime and alkali ratios are very similar in the Jackson sheet quartz porphyries, and in typical dacites, so that in reality they constitute a group intermediate between typical quartz-porphyries and typical quartz-porphyrites.

	Dacites				Quartz-Porphyries		
	129	131	A	B	151	553	549
SiO - - - -	65.66	67.49	69.51	68.20	70.29	71.19	72.24
CaO - - -	3.64	2.68	1.71	4.33	2.30	2.87	3.40
K_2O - - - -	2.03	2.40	3.34	1.52	3.05	1.82	.39
N_2O - - - -	3.65	4.37	3.89	2.98	2.68	4.24	4.43

Dacites 129 and 131 are from Sepulchre Mountain,[1] and the two designated as A and B are from Lassen Peak, Cal.[2]

Nos. 151, 553 and 549 are from the area of the Jackson sheet.

These rocks with porphyritic quartzes seem usually to be intrusive in more basic igneous rocks, augitic porphyrites and amphibolite-schist. An exception to this rule is the rock of the south part of the Gopher Ridge, south of the Salt Spring Valley reservoir. This grades over into a porphyrite containing augite, and is probably older than quartz-porphyries 553 and 549 which occur at the west base of the range, and are almost certainly intrusive, and, as no analysis has been made of it, it should perhaps be properly called a quartz-porphyrite and not a quartz-porphyry, on the basis above stated.

Intrusive in the augite-porphyrite and tuff that forms the western ridge of the Bear Mountains is a dike of serpentine, originally a peridotite or pyroxenite.

We have then in the Jackson sheet area:

Intermediate - Augitic porphyrites — Effusive.
Basic - - - - Peridotite — Intrusive.
Acid - - - - Quartz-porphyry — Intrusive.

[1] Thirteenth An. Rep. U. S. Geol. Survey, p. 648.
[2] Bull. No. 9, U. S. Geol. Survey, p. 16.

The time relation of the peridotite and quartz-porphyry is not known to the writer.

At the south end of the Gold Belt in Mariposa county there is a very interesting series of igneous rocks, the oldest of which appear to be augite-porphyrites and their tuffs, and their dynamometamorphic derivatives, some of which may be Palæozoic, and others Jura-Trias in age. They in no way differ from similar rocks that have been described above from the Jackson sheet area and elsewhere. These surface augitic volcanics are interbedded with schists and slates, and the entire series is cut off and metamorphosed by the granite a little south of the town of Mariposa (see Plate VII.) About Cathey Valley and westward from there to Hornitos are considerable areas of a dark granular rock some of which is seen under the microscope to be typical diabase with ophitic structure. In portions of the area the augite is replaced by brown hornblende, and the rock is then an ophitic diorite. No. 446, Sierra Nevada collection, probably represents nearly the average composition of this diabase. This specimen is from a dike by the road northeast of Hornitos. It is composed of augite and hornblende apparently intergrown, in which are imbedded feldspar laths. The area about Cathey Valley forms much the largest area of true diabase known to the writer in the Sierra Nevada. As the rock occurs in dikes in the greenstone tuffs and schists (augitic tuffs and their derivatives), it is evidently younger than at least a portion of the greenstone series.

Forming the high ridge east of Cathey Valley, and abutting against the coarser hornblendic granite that cuts off the slate series south of Mariposa, is a fine-grained granite in places practically an aplite. This fine-grained granite may be but a modification of the coarser granite, but is thought to be later. Ferro-magnesian constituents are rare in the larger part of the area, much of which may be called a soda-aplite (see analysis No. 413). Analysis No. 369 is of the coarser granite, from the Chowchilla River, and from the west edge of the same granite mass that cuts off the Mariposa slates west of the town of Mariposa, metamor-

ANALYSES OF PRE-TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	PORPHYRITE.	AUGITIC TUFF.	MELAPHYRE?	PERIDOTITE.	DIABASE.	QUARTZ-MICA-DIORITES (GRANODIORITES).			HBL.-MICA PORPHYRITE.	PORPHYRITIC GRANODIORITE.	APLITES.		DIORITE (?)
	25 S. N.	19 S. N.	26 S. N.	325 S. N.	446 S. N.	71 S. N.	303 S. N.	369 S. N.	304 S. N.	39 S. N.	413 S. N.	161 S. N.	250 Butte.
SiO_2	68.58	54.66	49.24	44.81	51.32	67.33	68.65	62.62	66.65	66.28	74.21	76.03	57.87
TiO_2	.57	.67	.96	1.88	1.23	.36	.28	.55	.33	.54	.30	.07	.53
Al_2O_3	13.04	15.85	14.79		15.28	15.93	16.34	17.51	17.61	16.03	14.47	13.39	16.30
Cr_2O_3	..	..	..	.20	..	..	..	..	..	..	..	..	..
Fe_2O_3	.26	1.82	1.52	1.98	.47	1.90	.93	.49	.93	1.80	.35	.48	1.71
FeO	3.40	5.12	8.00	4.52	8.59	1.59	1.48	4.06	1.67	1.88	..50	.31	3.86
MnO	.15	.18	.18	.13	..	.09	.08	.05	.07	.05	none	trace	.08
NiO	..	..	..	.09	.16	..	..	..	..	..	..	..	..
CaO	3.22	8.75	10.74	6.58	11.58	4.09	3.07	5.49	4.44	3.75	1.71	1.28	5.53
SrO	strong trace	trace	trace	none	faint trace	trace	.07	trace		trace	trace	trace	trace
BaO	.10	.04	.04	none	none	.08	.09	trace	.12	.08	none	.04	.05
MgO	1.01	5.64	6.89	30.91	7.25	1.63	1.29	2.84	1.26	1.12	.28	.05	5.50
K_2O	1.90	.47	.88	.15	.22	2.46	1.85	1.76	1.70	3.49	.10	5.18	.75
Na_2O	4.94	3.46	2.76		2.92	3.76	4.85	3.49	4.59	4.10	7.62	2.98	5.01
Li_2O	none	none	trace	..	faint trace	trace	trace	trace	trace	trace	trace	none	trace
H_2O below 110° C.	.16	.25	.20	.15	.06	.19	.24	.22	.03	.11	.15	.15	.26
H_2O above 110° C.	1.00	2.48	2.97	6.88	.95	.66	.62	.92	.41	.39	.23	.34	2.40
P_2O_5	.20	.15	.17	.02	.25	.11	.15	.12	.18	.30	.07	.03	.27
CO_2	1.31	.39	.90	1.79	..	..	..	..	..	..	..	..	..
FeS_2	.15	.09	..	..	..	..	..	..	..	..	..	..	..
	99.99	100.02	100.08	100.18	100.28	100.18	99.99	100.12	99.99	99.92	99.99	100.33	100.12

phosing them near the contact into mica and andalusite schists. In Yaqui Gulch some of the latter contain impressions of shells of *Aucella erringtoni*, Gabb, proving their upper Jurassic age. No. 399 is the fine-grained granite from Agua Fria Creek and not far from its contact with the coarse granite. Its mineral composition is not greatly different from that of the coarse granite as represented by No. 369. It is microscopically a micropegmatite with minute foils of brown mica gathered in groups. No. 413 is a white medium-grained rock, and a fair sample of the larger part of the area. It is composed of feldspar and some quartz plainly discernible as such, with a large amount of micropegmatite. In Cathey Valley and to the southeast of it, the diabase before described and the fine-grained soda-granite come in contact, forming a zone of contact-breccia in places more than a mile wide. The fragments of diabase are cemented together by white feldspathic material presumably from the granitic magma, indicating the later age of the white granite.

The augitic porphyrites of Mt. Bullion, north of Mariposa, are cut by a dike of serpentine, doubtless originally a peridotite.

Near Mormon Bar, south of Mariposa, is a dike of hornblende-porphyrite in the coarse granite.

The succession of the old igneous rocks in the Mariposa region is then, so far as made out, as follows:

Augite-porphyrite, chiefly tuff, effusive.

Intrusive:
- Diabase,
- Serpentine,
- Coarse granite (quartz-mica-diorite),
- Fine-grained granite (aplite),
- Hornblende-porphyrite.

As bearing on the age of the hornblende-porphyrite, it might be stated that at many points the granite and other rocks are cut by dikes of a dark rock containing original hornblende, some occurrences of which are granular in structure and allied to diorite, and others have a distinct groundmass and are more correctly called hornblende-porphyrite. An analysis of one of these (No. 250 Butte county collection) is given in the table. This is apparently holocrystalline, but the feldspar between the

idiomorphic hornblendes has crystallized in ill-defined branching forms. In the feldspathic material there are numerous minute green dots that appear to be chlorite. The analysis corresponds closely to that of the augitic tuff (19 S. N.) and to the composition of some pyroxene-andesite except that soda is greatly in excess of potash.

There are abundant dikes of fine-grained white granites (aplites) in the coarse granite of the Sierra Nevada. These in general have very nearly the composition of typical granites. They contain, as a rule, very little mica or hornblende. An analysis of one of these dikes is given in the table (No. 161 Sierra Nevada collection). The specimen was taken two miles southeasterly from Deadman's Peak, in the area of the Downieville sheet. It will be observed that the rhyolites, Nos. 126 Amador and 365 Plumas, have practically the same chemical composition as the aplite.

The volcanoes of Jura-Trias time in the Sierra Nevada appear to have been much more active than those of Palæozoic time, judging from the evidence offered in the preceding pages, and from that exhibited by the maps of the Gold Belt now being issued.

Following the Jura-Trias there seems to have been a long period during which the volcanic action was quiescent. This period apparently comprised most of Cretaceous and Eocene time.

The main facts concerning the age and succession of the Tertiary lavas of the Sierra Nevada have already appeared in print,[1] and only a short statement will be here inserted, together with some additional information obtained lately.

The first Tertiary eruptions, the relative age of which is clear, occurred apparently in Miocene time. These consisted of flows of rhyolite, which filled many of the old river valleys, but do not appear to have covered the higher ridges. The Miocene age of

[1] Am. Jour Science, Vol. XLIV., pp. 455–459; Am. Geol., Vol. XI., pp. 309–316; and the Fourteenth An. Rep. of the Director U. S. Geol. Survey, pp. 493–495.

the rhyolite-flows is shown by the plant remains occurring chiefly in clay beds of the Neocene Auriferous gravels with which the rhyolitic material is associated. Some of these clays have been thought themselves to be decomposed rhyolitic material. These plant remains, chiefly leaves, have been studied by Lesquereux, Ward, and Knowlton. Professor Lesquereux, it is true,[1] first considered the plants from the Auriferous gravels to indicate a Pliocene age for the containing beds, but in a more recent report[2] he refers other plants from the same, or possibly a somewhat later horizon, to the Miocene.[3]

Analyses of two rhyolites are given in the table (Nos. 126 Amador county, and 365 Plumas county). A number of partial analyses have been made of rhyolites from other localities, and all show a remarkably uniform silica, lime, soda, and potash ratio.

In Butte and Plumas counties there are extensive tables of a dense fine-grained black basalt, represented in the table of analyses by No. 276 Plumas county, and No. 18 Sierra Nevada. At many points the tables of this basalt are capped with andesite-breccia, showing that it is earlier than the andesite. Its age relative to the rhyolite is not known to the writer, but it is thought to be later, since the gravels which it covers at some points appear to belong to later channels than those covered by the rhyolite. Still, at Sawpit, northwest of Onion Valley (Downieville atlas sheet), this older basalt covers the older white quartz gravels, and on the Oroville Table Mountain it caps the Ione formation.

After the rhyolite and older basalt flows there was a period of erosion before the main andesite eruptions. These were of hornblende-pyroxene-andesite, an analysis of an average sample of which is given in the table (No. 72 Sierra Nevada collection). Much of the andesite occurs in the form of a tuff or breccia, and

[1] Memoirs Museum of Comp. Zoöl., Vol. VI., No. 2, p. 54.

[2] J. S. DILLER, Eighth An. Rep. U. S. Geol. Survey, p. 419.

[3] The age of the Auriferous gravels is discussed in a paper by DILLER (JOURNAL GEOLOGY, Vol. II., pp. 32–54) and in a paper by the writer to appear in the American Geologist, June 1895.

ANALYSES OF TERTIARY IGNEOUS ROCKS.

SPECIMEN NUMBER.	Rhyolite.		Older Basalt.		Table Mt. Basalt.	Hbl.-pye. Andesite.	Hbl.-Andesite.	Late Pyroxene-Andesites.				Qtz-Andesite.	Late Doleritic Basalt.	
	126 Amador	365 Plumas.	276 Plumas.	18 S. N.	36 S. N.	72 S. N.	16 S. N.	362 S. N.	1829 Cascade Range.	209 S. N.	661 S. N.	626 S. N.	311 Plumas.	314 Plumas.
SiO_2	73.23	71.39	50.56	50.66	56.19	58.47	60.20	59.34	68.12	66.94	56.90	60.02	53.91	52.81
TiO_2	.09	.17	1.71	2.39	.69	.51	.57	.32	.25	.30	..	.42	.52	.84
Al_2O_3	12.73	14.13	14.71	13.97	16.76	18.80	17.21	17.61	16.24	16.49	..	16.07	17.95	16.60
Cr_2O_3	..	..	..	..	..	..	..	..	none	..	..	trace	..	..
Fe_2O_3	.99	.63	3.54	2.55	3.05	3.34	3.12	3.63	1.26	1.41	..	2.17	2.21	2.66
FeO	.16	.37	8.90	10.20	4.18	2.64	2.69	2.28	2.08	1.87	..	3.46	4.80	6.13
MnO	trace	trace	.13	.29	.10	.13	.12	.12	.10	.13	..	.10	.10	undet.
NiO	..	..	..	trace	..	..	..	..	..	..	..	none	..	..
CaO	.61	1.01	7.58	8.08	6.53	6.60	6.04	6.45	3.80	4.77	7.83	7.01	10.40	10.14
SrO	none	trace	trace?	trace	strong trace	.05	trace	.04	.02	.05	..	trace	trace	trace
BaO	.02	.09	.25	.22	.19	.09	.11	.11	.09	.07	..	.08	.05	.03
MgO	.22	.08	4.07	4.45	3.79	2.69	3.18	3.50	1.35	1.98	..	4.57	5.52	6.12
K_2O	5.17	5.69	2.10	1.95	4.46	2.01	1.44	1.94	2.54	1.65	1.37	1.59	1.34	1.05
Na_2O	1.91	2.89	2.94	3.32	2.53	3.58	3.35	3.40	3.89	3.88	3.24	3.55	2.90	2.79
Li_2O	trace	trace	trace?	none	trace	trace	trace	trace	trace	trace	..	none	trace	trace
H_2O below 110° C.	.53	.42	1.06	.27	.34	.14	1.12	.64	..	.35	..	.24	.20	.38
H_2O above 110° C.	4.51	3.32	1.12	.43	.66	.92	1.18	.74	.40	.22	..	.45	.20	54
P_2O_5	.02	.03	1.14	1.01	.55	.22	.17	.25	.14	.12	..	.17	.21	.23
SO_3	..	..	..	Cl..02	..	..	..	..	..	..	..	SO_3.06	..	..
	100.19	100.22	99.81	99.81	100.02	100.19	100.50	100.37	100.28	100.23	..	99.96	100.31	100.32

appears to have issued from fissures near the summit of the range, mixed with water, forming enormous mud flows which covered a large part of the western slope of the range. At Poker Flat (Downieville atlas sheet) Canyon Creek cuts across a huge fissure filled in part with rubble of the adjacent rocks, but chiefly with fragmental andesite. This was at first taken to be evidence that the mud flows became such before issuing from the inner regions, that is to say, the volcanic material was thought to have been broken and mixed with water within the earth. The creek has cut to a depth of 1000 feet or more through this fragmental dike, without reaching the bottom of it. During the past season, however, another similar occurrence was found, where it is plain that the fissure was filled from above. This second instance is about one and one-fourth miles south of Cammel Peak (Bidwell Bar atlas sheet), in the canyon of Fall River. The stream has cut into this second fragmental dike of andesite-breccia to the depth of about 500 feet, and in the dike material in the bed of the river are imbedded numerous fragments of fossil wood. These pieces of wood must have been washed into this fissure from the surface together with the andesitic material in which they are imbedded. The specimens of wood collected were referred to Professor F. H. Knowlton, who reports that "it is a *Sequoia* of the redwood, or *S. sempervirens* type. The wood is not well enough preserved to enable me to say that it is the same as the living redwood, although it is undoubtedly near it."

Fragmental volcanic rocks are usually supposed to have been formed by explosive action, the material being thrown out as fragments and ashes, which, falling on the surrounding land, or in bodies of water, would in the former case assume a roughly and in the latter a definitely stratified shape. But this does not seem to form an adequate picture of the Pliocene andesitic eruptions of the Sierra. As before stated, the fragmental andesite appears to have been mixed with water, perhaps derived from melting snow at or very near the sources of the eruption. But however these mud flows were formed, on their course down the slopes of the range they caught up much foreign material. Silici-

fied trunks of both deciduous and coniferous trees, bowlders of granite, some of them tons in weight, and pebbles and fragments of nearly all the older rocks of which the Sierra Nevada is composed, are found imbedded in the andesitic material.

Along the east side of the Great Valley of California these andesite-tuffs grade into well-stratified material containing abundant rolled sand grains, and such areas may be regarded as water deposits. A most remarkable fact has been noted by the writer in regard to these tuff areas, and that is that wherever the original top layer of the beds has been preserved this is, so far as observed, a distinct breccia, composed chiefly of angular fragments and blocks cemented by ashes, while below are layers of

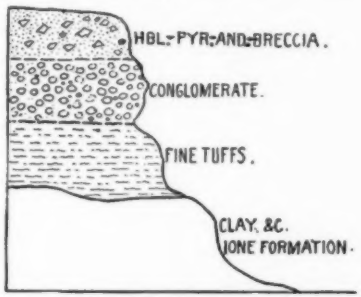


FIG. 3. Lava-capped hill four miles west of Ione. Elevation about 400 ft. above base.

fine tuff and volcanic conglomerates. The accompanying section (Fig. 3) represents the layers composing a flat-topped hill about four miles west of Ione, in Amador county.

With variations as to the layers of conglomerate and tuffs in their number and thickness, this section may be verified at a great number of points in the foothill region. The andesite of the breccia eruptions is a coarse-grained rock. It is shown in the table of analyses by No. 72 Sierra Nevada, which came from the southwest base of Mt. Ingalls. No. 16 Sierra Nevada is a massive occurrence of a similar coarse andesite, but differs from No. 72 in containing hornblende to the exclusion of pyroxene.

In the area of the Downieville and Bidwell Bar atlas sheets

are numerous bodies of a dense fine-grained gray lava, which usually weathers with a slaty fracture, the apparent cleavage being often vertical. The rock is composed of plagioclase, augite, a slightly pleochroic rhombic pyroxene, and grains of magnetite. The feldspar, augite, and rhombic pyroxene are in the form of minute elongated prisms or laths, and this is true of the rock at widely separated localities, and the laths of all are nearly of the same size. About half a gram of No. 661 powdered and treated with HCl by George Steiger yielded no gelatinous silica, but nevertheless there appears to be some glass present.

Three analyses are given in the table of this pyroxene-andesite. The analysis of No. 1829 Cascade Range collection[1] is of a specimen collected by Mr. Diller, from the west summit of Crater Peak (Lassen Peak atlas sheet); No. 209 Sierra Nevada is from the high point one and one-fourth miles northeast of Goodyear's Bar; and No. 661 is from Franklin Hill (Bidwell Bar atlas sheet). The analyses of 1829, and 209 are by Dr. Hillebrand, and the partial analysis of 661 is by Dr. Stokes. In the vicinity of Poker Flat are numerous dikes of another fine-grained andesite very similar in general appearance to the variety just described. It differs in being frequently columnar, and microscopically in containing a little hornblende and in the feldspars being less uniform in size and shape. At one point on the summit of the ridge south of Poker Flat a dike (No. 631 S. N.) of this rock cuts the hornblende-pyroxene-andesite-breccia. Another and larger dike cuts the pre-Tertiary rocks east of Poker Flat. It crosses Canyon Creek just east of the mouth of Illinois ravine, and to the southeast of Poker Flat forms a conical butte showing columnar structure. An analysis of the latter dike is given in the table (No. 262 S. N.). This andesite is therefore later than the hornblende-pyroxene-andesite-breccia. The exact relative age of the similar fine-grained andesite (Nos. 1829, 209 and 661) is still in doubt, but it is thought to be of about the same age as the andesite (Nos. 631 and 262) just described.

The rock called quartz-andesite (No. 626 S. N.) in the table

[1] Bull. No. 60, U. S. Geol. Survey, p. 157, No. 19.

of analyses of Tertiary rocks is not a dacite. The quartzes are much corroded and surrounded with reaction rims of pyroxene microlites. They may perhaps be regarded as inclusions. The rock has a pilotaxitic structure, and seems related to the fine-grained pyroxene-andesites. It forms a flat-topped hill on the ridge two miles northwest of Downieville.

Following the andesite eruptions we have at many points flows of basalts. Some of these, as, for example, the coarse doleritic basalts of Mt. Ingalls in Plumas county, are believed to belong to early Pleistocene time, for the eruptions seem to have occurred after the present drainage system was partly formed. However, on the north side of the mountain glacial striæ are to be seen on the lava, showing the flow to have taken place before the close of the Sierra Nevada glacial epoch. The doleritic basalt is represented in the table of analyses by Nos. 311 and 314 Plumas.

There are at many points isolated buttes and dikes of fine-grained basalts that do not resemble closely either the older basalt above described or the Pleistocene doleritic basalt. There is usually abundant olivine in these rocks, but their groundmass is much finer grained than that of the doleritic basalt. Their age is presumed to be Pleistocene. A dike of one of these rocks cuts the coarse andesite, and the underlying gravel of the point sometimes called Mt. Etna, one mile northeast of Mt. Fillmore (Downieville sheet) by the road to Johnsville, and similar dikes cut the Neocene fragmental material exposed on the southeast slope of Mt. Fillmore.

To the north of the Sierra Nevada at Cinder Cone,[1] near Lassen Peak, and about Mono Lake[2] just to the east, as well as in the Coast Range to the west near Clear Lake,[3] craters exist that retain nearly or quite their original forms. These volcanoes are without doubt of late Pleistocene age. Within the Sierra Nevada, however, if the range be limited as suggested in the beginning of

[1] Bull. No. 79, U. S. Geol. Survey, by J. S. Diller.

[2] Eighth An. Rep. Director U. S. Geol. Survey, pp. 378–389.

[3] Monograph XIII., U. S. Geol. Survey, p. 246.

this article, no eruptions are known to have occurred since early Pleistocene time.

The succession of the Tertiary volcanic rocks is then as follows:

ACID - - - - - - - -	Rhyolite — massive and fragmental.
BASIC - - - - - - - -	Older basalt — always (?) massive.
INTERMEDIATE - - - -	Hornblende-pyroxene-andesite — chiefly tuff and breccia.
INTERMEDIATE TO ACID -	Fine-grained pyroxene-andesites — massive.
BASIC - - - - - - -	Doleritic basalts — massive.
BASIC - - - - - - - -	Other basalts — massive.

This succession does not accord with the law of Richthofen nor with Iddings' law, but it should be noted that the record here given is an imperfect one.

According to Dr. James Blake,[1] there is a variety of volcanic rocks in the Puebla Mountains in Northern Nevada forming successive flows, the relative age of which is very clear, as the series is finely exposed. Dr. Blake made some chemical determinations of the igneous rocks, but they do not appear to have been studied microscopically. Indeed, at that time (1873) the microscope was in little use in rock investigation. His conclusion as to the succession is that it does not accord with Richthofen's law, but the series he describes obviously needs further investigation.

Iddings' law[2] is perhaps the latest that has been formulated with great care and after a consideration of the succession in many parts of the world, with a large amount of original research based on extensive field study and collections at various volcanic centers in the West. It is as follows:

> The variation in the composition of igneous rocks, which constitute a series of eruptions at any volcanic center, is the result of the chemical differentiation of some intermediate magma. The composition of the intermediate magma may be different in different centers of eruption and in different regions, and it will be shown subsequently that the intermediate magma of any particular center may itself be the result of a differentiation of a more ancient magma or of a primary uniform magma, if such a thing can be shown to have existed.

[1] Proc. Cal. Acad. Sci., Vol. V., pp. 210–214.

[2] Bull. Phil. Soc., Washington, Vol. XII., p. 151.

Brögger in a late paper on the basic igneous rocks of Gran, in Norway, writes as follows:[1]

> We have consequently in the basic rocks of Gran a remarkable example of the fact that one and the same magma *partly* without essential differentiation has been pressed up to a higher level, and there has crystallized out as large boss-masses (in the form of olivine-gabbro-diabase), *partly* has been differentiated at a deeper-seated level into a basic magma (which by its outburst has formed sheets and dikes with porphyritic structure, camptonites), and into a more acid residuary magma (which in the final eruptions has given rise to sheets and dikes of bostonite). This differentiation (into camptonites and bostonites) has partly also taken place in the dike and sheet-fissures themselves *after* passing up into a higher level.

This certainly confirms Iddings' law in a remarkable degree.

The chemical analyses of the igneous rocks of the Sierra Nevada given in the two tables, pages 403 and 407, are arranged as nearly as the writer is able in their order of succession. Considering now the Sierra Nevada as a whole as a petrographic province, there are certain relations which seem to suggest that Iddings' law may be applied here.

The oldest of the pre-Tertiary rocks which have a wide distribution are the augitic tuffs and breccias. These are chiefly of an intermediate character. The serpentines (originally peridotites and pyroxenites) are at a number of points clearly intrusive in, and therefore later than, these augitic tuffs. It seems to be also true that the quartz-mica-diorite (granodiorite) is later than the serpentine. This relation has already been noted[2] to the southeast of Placerville, and the quartz-mica-diorite of Indian Valley (Downieville sheet) sends out a dike-like protrusion into the serpentine where exposed in the bed rock of the Indian Hill gravel mine. In the bed of Mill Creek, one and one-half miles northeast of Big Bar Hill (Bidwell Bar atlas sheet), a dike of biotite-granite cuts the tremolite and chlorite schists which are altered forms of pyroxenites, and are in this section associated with serpentine as part of the same rock mass. About two and one-half miles south of Big Bar Hill

[1] Quart. Jour. Geol. Soc., Vol. L., p. 29.

[2] See Am. Geol., Vol. XI., p. 310.

there are streaks of serpentine, amphibolite and quartz schists forming one series which is cut off by a protrusion of the large Merrimac granite area. The succession of the most abundant of the pre-Tertiary rocks of the Sierra Nevada would then be:

INTERMEDIATE	Augitic porphyrites and their tuffs — effusive.
BASIC	Peridotites and Pyroxenites — intrusive.
ACID	Quartz-mica-diorites — intrusive.

Brögger has introduced a term that promises to be of much use to petrographic science. He writes:[1]

> For rock-types, differentiated out of a common magma, I propose the name "complementary rocks;" camptonites and bostonites are then such complementary rocks.

The serpentine, a very basic rock, and the quartz-mica-diorite are thus perhaps later differentiations from the intermediate magma of the augitic porphyrite eruptions. It is obviously unsafe, however, to generalize on the meager data presented as to the age of all of the augitic tuffs, serpentines, and granites of the Sierra Nevada. Instead of there being one series of these pre-Tertiary rocks, it is much more probable that there are two, a Palæozoic and a Jura-Trias series, and it is far from improbable that the succession is more complicated than represented here.

Later than the quartz-mica-diorite and serpentine are the aplite dikes or veins and the late hornblende-porphyrite dikes, and these may possibly be "complementary rocks" also. Both are nearly of an age, but they are not found together, so far as the writer has observed. The dikes of hornblendic rock are abundant in the Spanish Peak and the Merrimac (Bidwell Bar sheet) and the West Point (Jackson sheet) granitic areas; and the aplite dikes are common in most of the granitic areas, but as before stated are not associated with the hornblendic dikes.

H. W. TURNER.

[1] Quart. Jour. Geol. Soc., Vol. L., 1894, p. 31.

THE STRATIGRAPHY OF THE CALIFORNIA COAST RANGES.

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INTRODUCTION.

In a recent publication the writer presented a résumé of the present state of knowledge of the geology of the California Coast Ranges.[1] It is intended to devote the present article partly to a more detailed statement of views expressed in that paper on the relation of the Miocene, Upper and Lower Cretaceous to each other, which could not be fully discussed for lack of space, and partly to the presentation of additional evidence in support of the writer's published views concerning the existence of a pre-Cretaceous (pre-Knoxville) series of rocks in the Coast Ranges. Most of the observations on which the opinions presented are based were made during the summers of 1891–2–3. Valuable additions were made the past fall, when in company with Mr. F. M. Anderson, a student in Stanford University, a three weeks' trip was made through the Santa Lucia Mountains in Monterey and San Luis Obispo counties.

[1] Bull. Geol. Soc. Am., Vol. VI., 71–102.

CRYSTALLINE BASEMENT COMPLEX.

Considerable areas of granite, crystalline schists, and limestone appear at many points in the Coast Ranges between Point Reyes and Ventura county. No information has yet been gained of the age of any portion of this basement complex, beyond the fact that it underlies unconformably the most ancient uncrystalline rocks which are probably not older than the Jurassic. It would appear that the granite cannot be correlated with that which was irrupted at the close of the Jurassic in the Sierra region. It seems highly probable, from our present knowledge, that a long period of erosion, during which these crystalline rocks were much more prominently exposed than at present, ensued between the upheaval and metamorphism of the schists and limestones, and the deposition of the lowest uncrystalline strata.

GOLDEN GATE SERIES.

Definition.—Between the lowest recognized Cretaceous and the basement complex is a series of rocks separated from both by nonconformities, and everywhere characterized by rather peculiar lithologic features. For this collection of strata, consisting chiefly of jasper, sandstone, shale, and slate, typically developed about the entrance to San Francisco Bay, the designation Golden Gate series is proposed. According to our present knowledge these rocks form a conformable series of strata with a remarkable similarity of character through their whole extent. The scanty fauna thus far known indicates that it does not embrace a great range of geological time, although its thickness is very considerable. The series has been recognized by the writer from central Santa Barbara county northwestward through the Coast Ranges to the Klamath Mountains. On the western slope of these mountains it has been traced to the Oregon line, and it undoubtedly extends farther. Until recently the series has been considered, by all geologists who have published results of work in the Coast Ranges, not older than the Knoxville, of which it has often been thought to be a metamorphosed portion. In 1892 the writer first advanced the view that these rocks were

not a portion of the Knoxville,[1] but that they underlaid it unconformably. Since then in other publications[2] additional evidences have been given of the geological independence of this series, of its distinct lithological character, and of its extent in the Coast Ranges. To the writer the evidences supporting this view seem to be conclusive. Nevertheless, the old view that these rocks constituted a metamorphosed portion of the Knoxville has been accepted so long, and has become so current in geological literature, that the new one has been looked upon with more or less doubt. The writer ventures to assert, however, that if the geology of the Coast Ranges had never been touched until today, the confounding of the Knoxville with the older series beneath never would have occurred. In the light of these conditions it has seemed best to continue to put on record all observations which would aid in bringing out a full recognition of the important fact that there is an uncrystalline series of rocks in the Coast Ranges beneath the Knoxville. The importance of the correct classification will be understood when it is stated that the strata included in the Golden Gate series extend for a distance of 500 miles through California, and for an unknown distance in Oregon. The recent field work in Monterey and San Luis Obispo counties has been so fruitful in positive results that the existence of a pre-Knoxville series of uncrystalline strata must be considered proved.

Lithologic character.—One of the distinct features of this series of rocks is its peculiar and comparatively uniform lithologic character. In general it is so different from that of any of the younger formations that it can be used as a criterion of distinction by one familiar with the general character of the formations in the Coast Ranges. This becomes of the greatest value when there is taken into consideration the scarcity of fossils and the rare occurrence of distinct contacts. The jasper has until recently been considered a metamorphic rock. In a paper read before the Geological Society last August, the view was advanced

[1] American Geologist, Vol. IX., 153–166.

[2] American Geologist, Vol. XI., 69–84. Bull. Geol. Soc. Am., Vol. VI., 71–102.

by the writer that the jasper is not metamorphic, but that it is formed to a considerable extent of the remains of siliceous organisms of the radiolarian type. This opinion was based on the study of a number of thin sections of the rock from widely separated portions of the Coast Ranges. F. Leslie Ransome has recently announced the discovery of the first radiolarian remains found in a state sufficiently well preserved for description. Many specimens of jasper were collected on the recent trip through Monterey and San Louis Obispo counties, and nearly all showed the radiolaria visible to the unaided eye. The best were obtained from a large outcrop of greenish white jasper on the Eagle Ranch, six miles northwest of Santa Margarita. A microscopic study shows that portions of this rock are made up almost wholly of radiolaria which are in a better state of preservation than any previously found, fifteen or more specific forms being made out. The jasper beds vary from a few feet to more than a hundred feet in thickness, and exhibit more or less distinctly a banded structure. The bands are often contorted so as to present a beautiful wavy appearance. The accompanying illustration is from a photograph of a magnificent outcrop on the coast of Monterey near the mouth of the Sur River. It illustrates both the banding and the wavy structure. Comparatively uniform conditions must have existed over the whole of the area covered by the Golden Gate series, where the rocks were being deposited, for the jasper beds are found almost everywhere that the rocks of this series are exposed. Similar conditions did not obtain during the Cretaceous, for jasper is not known in any beds of that age on the Pacific coast. The series of beds of which the jasper forms such a striking feature undoubtedly possess a great thickness, but they have not yet been studied sufficiently in regions where the greatest development occurs to admit of any definite statement of their thickness. It is not probable that the jasper is confined to one horizon in the series, and the strata have been so sharply folded, shattered, and crushed together by orographic movements, as well as by the intrusion of numerous eruptives, that its study is accompanied by uncommon difficulties. Sandstone

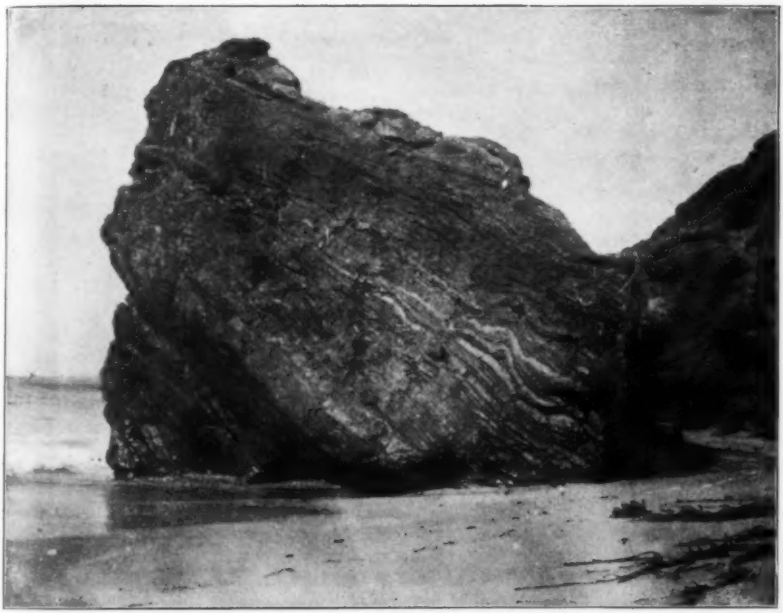

FIG. 1. Banded Jasper of the Golden Gate series, coast of Monterey county, California, near the mouth of the Sur River.

forms the larger part of the series wherever the writer has investigated it. The sandstone strata are often thick-bedded, which fact, taken together with the distortion undergone makes it very difficult to determine the bedding in small outcrops. Shale or slate occurs in subordinate amount, as thin layers between the sandstone strata, or more rarely in thick beds as in some portions of the Santa Lucia Mountains and the northern Coast Ranges.

Stratigraphic position.—The Golden Gate series as previously defined underlies unconformably the lowest known Cretaceous and rests on the crystalline basement rocks. It seems, for reasons to be mentioned, that no great lapse of time, geologically speaking, separated the deposition of the beds belonging to this series from the lowest Knoxville beds, but on the contrary the time interval separating it from the crystalline basement is very great. At numerous points along the coast of Monterey county this Golden Gate series rests on the granite and crystalline schists. For a distance of three or four miles in the vicinity of Slate's Springs it terminates below with a conglomerate which, on Hot Spring Creek, is 1000 feet thick.

The question of the relation between the Golden Gate series and the Knoxville is the all-important one. As far south as the fortieth parallel Mr. Diller has proved the existence of a series older than the Knoxville and separated from it by a nonconformity. Four miles east of Lower Lake the writer has observed an undoubted nonconformity between the *Aucella*-bearing shales and the older series. About Clear Lake the Chico rests unconformably on upturned masses of sandstone, jasper, and slate. In the Cañon of Capel Creek, Napa county, there are good evidences of a nonconformity between the Knoxville and an older series. In the Coast Range south of San Francisco the writer has observed the Chico at many points resting unconformably on a series of rocks lithologically very similar to that underlying the Knoxville farther north. The recent trip through the Santa Lucia Range resulted in the discovery of several distinct contacts between the *Aucella*-bearing Knoxville shales and an under-

lying series of jasper and sandstone. The most northerly known occurrence of the Knoxville beds in the Santa Lucia Range is on Pine Mountain opposite the town of San Simeon. The Knoxville beds here outcrop on the very summit of the range, being partly capped by liparite. They have an exposure of at least two miles from northwest to southeast and a width of a mile. The lower slopes of the mountain surrounding the beds consist of jasper, sandstone and dark, fine-grained eruptives. A section exposed along the grade of an old road crossing the mountain makes it very evident that the Knoxville overlies these rocks unconformably, but no good contacts were found there owing to the enormous amount of débris. On the southern slope the Knoxville beds are well exposed, dipping northerly at a gentle angle. To the east they are replaced by a ridge formed of hard sandstone and jasper, and in a little gulch eroded between these two formations, their relation to each other is distinctly shown. At one point the bottom and east side of the gulch consists of gray sandstone with thin, irregular layers of shale having a vertical dip and a north and south strike. On the west side the Knoxville shales, *Aucella*-bearing a few hundred feet above, appear in contact with the sandstone, dipping west at an angle of 40°. A short distance further up the gulch the Knoxville shales extend up to and overlie the gray sandstone with as marked a discordance in dip as that first noted. Less than one hundred feet away green jasper is interstratified with the sandstone.

Another area of the Knoxville beds occurs in the same range, north of the town of San Luis Obispo. The beds form much of the mountainous area extending from the railroad tunnel northwest for about fifteen miles. On the southwest these beds rest against a great serpentine ridge which forms one of the crests of the range. On the northeast they are underlaid by the sandstone and jasper of the Golden Gate series. At many points about the heads of Toro and Morro Creeks the Knoxville appears to have no great thickness, for it flanks the little hills and ridges of the Golden Gate series which project through it in the most

irregular manner. Numerous points were found where the contact was obscured by only a few feet of débris. The *Aucella* appeared widely distributed in the shales and sandstone, but its stratigraphic position could not be determined because of the complexity of the structure. On the summit of the range between Morro Creek and the Arroyo Atascadero a narrow arm of the Knoxville shales and sandstone is folded in vertically between ridges of the older series. The contact is plainly shown in the bed of a dry arroyo. Specimens of *Aucella* were obtained from a coarse sandstone blending into a conglomerate at a point which was apparently the lowest portion of the beds.

The Golden Gate series projects through the Knoxville in many places near the Eagle Ranch House. The former consists of jasper, sandstone and shale with large bodies of greenish, fine-grained eruptives. Absolute contacts showing an unconformable superposition of the Knoxville are rare because of the amount of soil everywhere present. More than a score of instances were noted where the contact between the two formations was hidden by only a slight amount of soil so that a few hours' work with a shovel would uncover it. The contacts already found, however, showing an unconformity, taken together with those where it is probable though not distinctly shown, and which would be accepted without hesitation by one thoroughly familiar with the two formations, establish on stratigraphic grounds the existence of an uncrystalline series below the Knoxville.

Faunal relations.—Fossil remains characteristic of a definite horizon have not yet been found in the Golden Gate series. This is a most remarkable fact when there is taken into consideration its extent, and the amount of study which has been given to it. The first fossil found in rocks which the writer would refer to this series is the *Inoceramus elliotti*, Gabb, from Alcatraz Island, obtained by Whitney. This was considered at the time as positive proof of the Cretaceous age of the San Francisco sandstone.[1] In the summer of 1892 the writer obtained several poorly preserved specimens of *Inoceramus* from a bed of black

slate at Slate's Springs on the coast of Monterey county. This locality was revisited the past fall in company with Mr. Anderson, and a collection made embracing five species of lamellibranchs and a number of plants. The former though somewhat crushed were well enough preserved for generic determination. Unfortunately they proved to be very puzzling and threw but little light on the question at issue. They were submitted to Mr. T. W. Stanton for determination and the following description is given by him: "The collection includes a large species of *Inoceramus*, a large *Homomya* (?), *Macrodon*, *Leda* and *Rhynchonella*, none of which can now be referred to described species. The *Inoceramus* seems to me the most important form in determining the age, as it is confined to the Mesozoic, and a species of this size and type is probably not older than the Jurassic and might be Cretaceous. *Inoceramus quatsinoensis*, Whiteaves, from the *Aucella*-bearing Cretaceous beds of Vancouver is a similar species. Taking this in connection with the statements of yourself and Mr. Anderson concerning the field and stratigraphic relations of the beds, the most reasonable inference would seem to be Jurassic. The other fossils apparently do not conflict with this reference."

In the absence of confirmatory evidence the *Inoceramus* from Alcatraz Island cannot be accepted as proof of the Cretaceous age of the strata there, and it is very probable that the horizon represented is the same or nearly the same as that of the Slate's Springs beds.

The recent discovery of radiolaria in the jasper of the Golden Gate series not only adds greatly to the interest of these rocks but also may aid in the solution of the age problem. Those found by Mr. Ransome and Professor Lawson, and submitted to Mr. Hinde for examination, are, according to his description, forms similar to those occurring in the jasper of the Upper Jurassic and Lower Cretaceous of Europe. A part of the European beds containing the radiolaria are believed to belong to the upper Jurassic, while opinion is divided as to the exact horizon of the others. The specimens obtained by the writer

from the Eagle Ranch resemble those from Angel Island, but the number of species is greater and the state of preservation better in many cases. In Vol. XXXI. of the Palæontographica Rüst gives a plate on which are figured a group of radiolaria from the red jasper of west Switzerland which belongs to the upper division of the Jurassic. A comparison of the figures on this plate with those in a slide from the Eagle Ranch shows a remarkable similarity of the forms. At least five forms in the slide are closely allied to those on the plate.

It will be seen that as far as faunal evidence is concerned the question cannot yet be considered as satisfactorily settled. This much can be said, however, that the fossil remains found on the one hand in the jasper in different portions of the series, and in the slates near its base on the coast of Monterey, indicate with a strong degree of probability that the series as a whole is not older than the Jurassic and may belong to its upper division. Some of the forms, especially that of the *Inoceramus*, are very closely allied to known Cretaceous species, so that if palæontology alone had to be relied upon the question is at present a puzzling one. When, however, in addition to the faunal evidence, there is taken into account the fact of the unconformable position of the series beneath the Knoxville, the writer believes that its horizon can be stated with a considerable degree of certainty as Upper Jurassic. It may be best to add here that the application of the term Jurassic to this series is based on the fact that the Knoxville is at present considered by palæontologists as belonging to the Lowest Cretaceous. The writer does not wish to be understood as contending in this or in other articles previously published for a Jurassic series *per se*, but for the recognition of the existence of an uncrystalline series underlying the base of the Knoxville.

Stratigraphic position of the beds at Slate's Springs.—Lithologically the strata are entirely different from any portion of the known Cretaceous on the Pacific coast. They are considerably metamorphosed and in places extremely distorted and broken. They stand nearly vertical and consist of alternating layers of

sandstone and slate. They are followed downward by a thick conglomerate, while other layers of similar conglomerate are exposed in the edge of the ocean. The whole series has an exposed thickness of 1500 feet from the base to the ocean cliffs, and extends an unknown distance beneath the sea. The slates and sandstones form a narrow belt, at times almost cut out by bodies of eruptive origin, for a number of miles down the coast. They gradually widen out to form the great area of pre-Knoxville rocks of the Santa Lucia Mountains in southern Monterey and northern San Luis Obispo counties. Four miles south of Slate's Springs and north of Big Cañon bodies of jasperoid rocks are associated with the sandstone. On the ridge south of Big Cañon are a number of outcrops of red jasper. At the mouth of Mill Creek is another body of jasper. Near the mouth of Vicente Creek slates outcrop along the cliffs facing the ocean, bearing the closest resemblance to those at Slate's Springs. A short distance south of Vicente Creek there are large outcrops of a banded red jasper. The Slate's Springs beds thus appear to be both stratigraphically and lithologically continuous with the Golden Gate series which on Pine Mountain underlies the Knoxville beds unconformably. Mr. Anderson, who has given considerable study to the Cretaceous of Oregon and northern California, agrees entirely with the writer with regard to the strongly marked lithological contrast between the strata at Slate's Springs and the Cretaceous, and their resemblance to portions of the Auriferous Slate series.

THE TIME INTERVAL BETWEEN THE KNOXVILLE AND THE GOLDEN GATE SERIES.

The great deformation exhibited by the Golden Gate series, its much higher degree of solidification and partial metamorphism, the numerous included bodies of eruptives formed prior to the deposition of the Knoxville, and the marked nonconformity between it and the Knoxville, all point to a time interval of considerable extent, during which there were violent disturbances terminating in its elevation and erosion. This interval may

represent a portion of the uppermost Jurassic or possibly the very base of the Cretaceous. Dr. White has represented graphically the position of the different divisions of the California Cretaceous in his Correlation papers. According to this the extreme basal portion of the Cretaceous is absent. The more recent work of Messrs. Diller and Stanton, which has been carried out with the greatest care, places the Knoxville at the base of the Cretaceous. This places the Golden Gate series in the Jurassic, and probably at a horizon which corresponds very closely with that represented by the Mariposa beds. Although the fauna at present known from the Golden Gate series is indeterminate in its time relations, as far as the Jurassic or Cretaceous is concerned, the pronounced nonconformity between it and the Knoxville must be taken into account. The interval necessary for the deformation, metamorphism and erosion of the lower series must have been considerable, and is to be correlated with that found by Mr. Diller to exist between the Upper Jurassic beds of northern and central California, and the Shasta-Chico series of the Sacramento Valley. The increasing mass of evidence is in favor of the views of Mr. Diller concerning the synchronism of the great revolution in the Sierras and the Klamath Mountains, which he holds took place near the termination of the Jurassic. Accepting this as true, as the writer has stated in former publications, a demonstration of the extension of this nonconformity southward also proves that the underlying rocks are at least as old as the Jurassic.

THE NONCONFORMITY BETWEEN THE CHICO AND KNOXVILLE IN THE SOUTHERN COAST RANGES.

In several papers the writer has expressed the opinion that there is evidence at many points in the Coast Ranges of the existence of a nonconformity between the Chico and Knoxville beds. This nonconformity is supposed to be due in part to a post-Knoxville elevation when numerous bodies of peridotitic eruptives were formed. As far as is known the Horsetown beds are absent from the Coast Ranges south of San Francisco. Until recently the Upper and Lower Cretaceous had not been

found together in that portion of the state, and their relation to each other was more or less a matter of inference. The contact which has just been found is on the Eagle Ranch in the Santa Lucia Range. The central portion of the range is there formed of Knoxville shales and sandstone carrying *Aucella*, the total width exposed being about three miles. The Knoxville is bordered on the west by a great dike of serpentine, while on the east a nearly hidden axis belonging to the Golden Gate series projects through it in numerous places. The Knoxville presents a very much disturbed condition, partly due to the dikes of serpentine. The Chico, consisting almost wholly of heavy-bedded sandstone, rises on the eastern slope, overlapping the Knoxville shales and capping portions of the first line of hills. It has not undergone the same amount of disturbance as the Knoxville and is nowhere folded in with it, appearing rather as a thin capping on an irregularly eroded surface. Fossils were sought for a long time in the sandstone without any result. Finally a number of poorly preserved specimens were obtained from the summit of a hill about one mile south of the Ranch House. The following is the list: *Baculites chicoensis*, Trask. *Trigonia evansana* (?), Meek. *Pectunculus veatchi*, Gabb, *Cucullaea sp.*, *Pentacrinus sp.* In a small ravine near the spot where the fossils were obtained there is a contact between the sandstone and the dark shales. This ravine extends up the west side of the hill making a slight depression nearly to its summit. The northern portion of the hill is capped with a thin layer of the Chico sandstone, dipping south at an angle of 30°. The sandstone extends to the bed of the ravine and is there exposed resting on the shales. The latter are well shown, not only underneath the sandstone but also on the slope of the hill south into which the dip of the sandstones would carry them. The sandstone has a very regular bedding while the shale underneath is so broken that the stratification is not distinctly visible. The spot was examined particularly with reference to the possibility of the phenomena being due to faulting, but no evidence of it could be discovered. Fossils were not found in the Knox-

ville near the sandstone, but at the base of the hill one-half mile distant, in strata which could be traced by continuous outcrop to the contact. On the north fork of the Atascadero, three miles northwest of this locality, is an *Aucella*-bearing stratum folded in between the older rocks. About 500 feet north of the vertical Knoxville shales is a hill capped with a body of Chico sandstone with only slightly inclined bedding planes. This hill lies directly in the strike of the shales, and although no contact is visible there can be no doubt of an unconformity.

THE RELATION OF THE SERPENTINE TO THE CHICO-KNOXVILLE UNCONFORMITY.

The absence of the Horsetown beds and the presence of numerous large bodies of serpentine favor the supposition of a break between the upper and lower divisions of the Cretaceous. Serpentine occurs intruding the Knoxville and older rocks at many points along the Santa Lucia Range. It seemed probable that such was the case on Pine Mountain although no good exposures were found. Near the Old Padre mine, west of Santa Margarita, the Knoxville shales in contact with the serpentine are considerably metamorphosed. On the Eagle Ranch a dike of serpentine has been cut on one of the grades, showing its intrusion in the Knoxville shales. The writer has never seen serpentine intruded in the Chico in any portion of the Coast Ranges, and all indications point to its formation during the interval between the deposition of the Knoxville beds and the Chico. In the southern Coast Ranges at least, the disturbance must have caused an elevation of the Knoxville, so that during the period represented by the deposition of the Horsetown beds in northern California, the former must have been above water and undergoing erosion.

THE NON-CONFORMITY BETWEEN THE MIOCENE AND THE CHICO-TEJON SERIES.

An examination of geological literature relating to the Coast Ranges shows that the Miocene has generally been held to have been deposited conformably on the Chico-Tejon series. This

question had not been studied in the southern Coast Ranges prior to the work done there by the writer. In that field numerous occurrences were noted where the Miocene unconformable overlaid the Chico, or Tejon, as the case might be. The non conformity was pronounced wherever contacts could be found, for a distance of 200 miles, through the counties of Ventura, Santa Barbara, San Luis Obispo, and Monterey. Topographically the southern portion of this region is very rugged and difficult of exploration. The deep cañons and brushy mountains rising 5000–7000 feet make access to it almost impossible except along the scattered trails. Geologically portions are quite complex but there are large areas where the Cretaceous, Lower and Middle Tertiary are the only horizons represented. The assemblage of strata belonging to the Upper Cretaceous and the Lower Tertiary, known in geological literature as the Chico-Tejon series, is particularly prominent in northern Ventura and southern Santa Barbara counties. The Miocene not only forms complete mountain ranges, as for example, the Santa Ynez, but also appears as fringes along the Chico-Tejon elevations and in detached areas almost on their very summits. Beginning in northern Ventura county the various localities will be described where the relation of the Miocene to the Chico and Tejon was observed. Pine Mountain in northern Ventura county extends in an east and west direction between Cuyamas River on the north and the Sespe on the south. It forms the northern portion of a great thickness of dark shales and sandstones which have a width, north and south across their line of strike, of nearly twelve miles. Fossils were collected from two localities on this section, but so complex is the structure that the exact position in the series was not determined, although it seems that they are from the upper portion. On the northern slope of Pine Mountain the following fossils were collected: *Meretrix horni*, Gabb; *Fusus remondi*, Gabb; *Neverita globosa*, Gabb; *Dentalium pusillum*, Gabb; *Turris varicostata* (?), Gabb; *Actæonella oviformis* (?), Gabb; *Turritella sp.* The horizon indicated is the Tejon. Near the head of the Matillija Cañon, about eight miles southward, there was collected the

following Tejon forms: *Crassatella grandis*, Gabb; *Meretrix horni*, Gabb; *Cardium sp.; Fusus martinez*, Gabb; *Dentalium cooperi*. The Sespe in its upper course has eroded a broad longitudinal valley in the center of this formation. North of the stream on the southern slope of Pine Mountain is a body of heavy-bedded light yellow sandstone, dipping north generally at a small angle. Where the Matillija trail crosses it there were found numerous specimens of *Astrodapsis whitneyi*, Remond; fragments of *Ostrea titan*, Con., and *Pecten discus*, Con. Four miles down the cañon Dr. Bowers[1] has collected twenty-five Miocene species from the same sandstone. Although the actual contact was not observed, there can be no doubt as to the unconformity. The Tejon and possibly Chico strata below being steeply inclined and much broken, especially south of the Sespe, while the Miocene sandstone dips very regularly to the north into the Tejon, forming the summit and north slope of Pine Mountain. Near the mouth of Santa Barbara cañon there is a series of sandstones, gypsum-bearing clays, and limestones resting unconformably against dark thin-bedded sandstones and shales of undoubted Cretaceous age, although no fossils were found at this point. South of the Perkin's Ranch on the slopes of the Cuyamas Range are numerous areas of light yellow heavy-bedded sandstones resting on or against dark sandstones and shales. Specimens of a Miocene *Pecten* and *Ostrea* occur in the upper beds at different points. The following Chico fossils were found in the deep cañon of the Sisquoc, between the Cuyamas Range and the San Rafael Mountains: *Inoceramus, sp.; Meekia sella*, Gabb; *Pectunculus veatchi*, Gabb; *Cinulia obliqua*, Gabb; *Baculites chicoensis*, Trask; *Cylichna costata*, Gabb; *Tellina ashburneri*, Gabb; *Dentalium stramineum*, Gabb, and an unknown crustacean. The strata consisting of dark shales and thin-bedded sandstones are steeply tilted and much broken. Stratigraphically they seem to belong with the lowest beds in Santa Barbara Cañon. The uppermost beds at the head of the latter cañon occupy the highest position in a great synclinal fold, appearing to be a continuation of the Tejon on Pine Mountain. South of the Sisquoc,

[1] Report Cal. State Mining Bureau, p. 763.

capping the high mountains between it and the Manzana River, is a large area of light yellow sandstone, apparently not greatly disturbed. Continuing up the Sisquoc these sandstones were finally observed outcropping on the bank in direct contact with the Cretaceous. The discordance in dip of the two formations is about 15°. There does not seem to be any doubt about the reference of the sandstones to the Miocene, as they correspond exactly to the known Miocene only a short distance to the north. In the lower end of the Cuyamas valley are horizontal strata of incoherent sandstones bearing *Ostrea titan* and a species of *Pecten*, while only a short distance below are steeply inclined conglomerates and sandstones referable to the Chico.

In a small tributary cañon of the Santa Ynez River, below the old Mission, is a contact between a body of dark shales, closely simulating the Knoxville, and light yellow sandstone. The sandstone rests on the shales with a discordance in dip of 20°. In the shales no fossils were found, but in the sandstone two species were obtained: *Ostrea panzana* (?) Con., and *Pecten pabloensis* (?) Con. That portion of the Santa Lucia Range lying in southern San Luis Obispo county consists largely of heavy-bedded sandstones and conglomerates, which according to our present knowledge are wholly referable to the Chico. Near the head of the Santa Margarita Valley specimens of *Trigonia evansana*, Gabb, and *Axinea veatchi*, Gabb, were obtained from the sandstone. Five miles farther north several specimens of *Venus lenticularis*, Gabb, were found in a nodular mass of limestone in the same sandstones.

An excellent section of the Bituminous Slate series (Miocene) is shown for many miles along the Arroyo Grande which has its source in the Santa Lucia Range. Near its head in the vicinity of Music are extensive beds of sandstone carrying *Ostrea titan*, Con., and *Astrodapsis whitneyi*, Remond. Fully 2000 feet below this sandstone in the same series of rocks is a considerable thicknesss of soft argillaceous sandstone containing the following Miocene species: *Pectunculus patulus*, Con., *Leda cælata*, Hds., and *Arca microdonta*, Con. Between 200 and 300 feet below

these fossiliferous beds the Miocene terminates in a soft, white sandstone. This rock rests against nearly vertical beds of hard sandstone and shale which without much doubt are referable to the Chico, as they can be traced by continuous outcrop to localities where fossils of that age were found.

A narrow belt of Miocene shales extends diagonally across the Santa Lucia Range from a point west of Templeton to the head of Santa Rosa Creek. On the north fork of the Arroyo Atascadero this shale is filled with fish remains and the mollusk, *Pecten peckhami*, Gabb. The shales overlie rocks of the Golden Gate series and dip nearly vertically. Directly in line of their strike rises a hill of Chico sandstone, the bedding of which is nearly level. The Miocene can be traced by outcrop to within a few feet of the Chico; it was evidently deposited on the eroded surface of both the Golden Gate series and the Chico. The same white shales occur on the Eagle Ranch about three miles southeast of this point. There they dip about 30° southwestward apparently resting on the yellow Chico sandstones whose outcrop was obtained within 150 feet of the shales. The sandstone shows at many places a uniform dip of 20° to 30° to the northeast. West of the white shales is a hill of jasper partly capped by the Chico sandstone. The dip of the shales at the base of the hill is such that if extended they would pass beneath the two older formations. All the phenomena shown here point to the deposition of the Miocene on the eroded surface of the Chico.

CONCLUSION.

The correct determination of the age of the Golden Gate series is one of the most important questions in Coast Range geology. The accumulating evidences are strongly in favor of the view of its Upper Jurassic age. There can no longer be any doubt as to the unconformable position of the series beneath the Knoxville, and the fauna indicates that it is not older than the Jurassic.

If future detailed examinations should prove that the Horsetown beds are absent from the southern Coast Ranges, there

must be postulated a considerable period during the middle of the Cretaceous in which that region was elevated and undergoing erosion.

The Chico-Tejon has a thickness of at least 20,000 feet in several places. We have no knowledge at present of a stratigraphic break in the series, but the direct superposition of the Miocene on the Chico in many localities lends some degree of probability to the view that a break exists.

The Miocene exposed on the Arroyo Grande has a thickness of from 5000 to 8000 feet. The succession of strata from the top downward is as follows: (1) Bituminous slate, (2) Sandstone carrying *Ostrea titan*, (3) Bituminous slate and argillaceous sandstone.

In the vicinity of the Eagle Ranch there is one of the most interesting associations of strata of different age to be found in the Coast Ranges. Four formations are present from all of which fossils were obtained: The Miocene, Chico, Knoxville and Golden Gate series, each being separated from the others by a nonconformity.

HAROLD W. FAIRBANKS.

BERKELEY, California.

STUDIES IN THE NEOCENE OF CALIFORNIA.[1]

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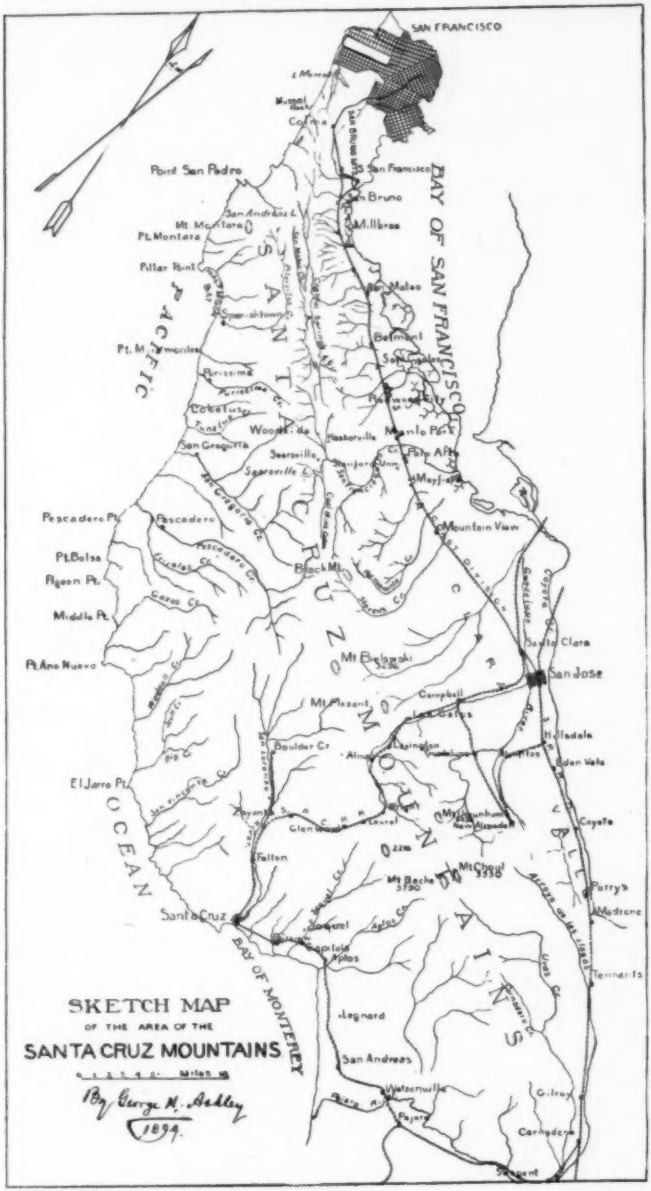
INTRODUCTION.

THE Santa Cruz Mountains, one of the Coast Ranges, lie just south of the city of San Francisco, and occupy a region about sixty-five miles long by twenty-five wide as a maximum. The whole region is an intricate series of ridges and narrow, deep valleys. The highest points rise nearly 4000 feet. The main axis has a northwest and southeast trend, and as the coast here lies nearly north and south, the ocean has cut a diagonal cross-section of its northern end, giving an excellent opportunity for the study of its history.

GENERAL GEOLOGY.

All around the edge of the mountains are nearly level plains formed partly by erosion, partly by the deposition of horizontal, unconsolidated Quaternary deposits.

[1] Abstract of a paper presented at Leland Stanford Junior University for the degree of Doctor of Philosophy.


SAN FRANCISCO
Point San Pedro
Mt. Montara
Pt. Montara
Pillar Point
Pt. Pescadero
Pescadero Pt.
Pt. Bolsa
Ayano Pt.
Middle Pt.
Pt. Ano Nuevo
El Jarro Pt.
Santa Cruz
BAY OF MONTEREY
OCEAN
PACIFIC
BAY OF SAN FRANCISCO
SANTA CRUZ MOUNTAINS
Mt. Bielawski
Mt. Pleasant
Mt. Loma Prieta
Mt. Umunhum
Mt. Copal
Mt. Bache
Mt. Madonna
Mt. Hamilton
Mountain View
Santa Clara
San Jose
Los Gatos
Saratoga
Campbell
Hollidale
Eden Vale
Coyote
Parry's
Madrone
Tennants
Felton
Boulder Cr
Zayante
Glenwood
Laurel
Zayante
Aptos
Soquel
Capitola
Leonard
San Andreas
Watsonville
Gilroy
Pajaro
Carnadero
Bryant
SKETCH MAP
OF THE AREA OF THE
SANTA CRUZ MOUNTAINS
Miles
By George H. Bailey
1894.

Unconformably below these deposits lies a series of sandy and clayey strata, partly consolidated, having locally a thickness of nearly a mile. This series, called recently by Professor Lawson[1] the Merced series, has been gently folded and has now been largely removed from the higher parts of the range. It is quite fossiliferous, and exhibits an interesting life history. In age it is mainly Pliocene, but appears to run into the Pleistocene above, and into the Miocene below.

Conformably below the Merced series is the Monterey series, one of the earliest of California formations to be studied and described. It is a great thickness of light-colored, bituminous shale, containing few fossils, and similar in structure to the Merced series. It is of Miocene age.

Unconformably below the preceding series, and having considerable prominence in the Santa Cruz Mountains, is a great series of sandstones, shales, and conglomerates, which we propose to call the Pescadero series. They consist in part of the San Francisco sandstone of previous writers. The section near Pescadero gives a questionable thickness of over 10,000 feet. They have been greatly disturbed and faulted. Their age has been shown to be in part Miocene, and is thought to extend down through the Eocene and possibly into the Cretaceous.

Still more prominent about San Francisco and through the Santa Cruz Mountains is a group of metamorphic and igneous rocks. They are cherts, sandstones, limestone, granite, serpentine, etc. They might be grouped together as the pre-Tertiary rocks of the Coast Ranges.

A small amount of Tertiary igneous rock occurs in the Santa Cruz Range.

STRATIGRAPHY.

Below is given a columnar section of the Santa Cruz Mountains. The formations there given will be briefly described, beginning with the oldest.

The metamorphics.—Under the term metamorphics may be included the beds of limestone occurring through the mountains,

[1] Univ. of Cal., Bull. Dept. of Geol., I., 143.

the granite forming the core of the range, the metamorphic sandstone, the thin-bedded chert, and the serpentine.

The limestone, whose age is unknown, occurs in two beds, extending southward from near Point San Pedro.

COLUMNAR SECTION OF THE SANTA CRUZ MOUNTAINS.

Pleistocene		Subaërial deposits. Marine deposits. Subaërial deposits.	*Elephas*, conifers.	Thickness 2000 + ft.
Pliocene	Merced Ser.	Fossiliferous beds of sandstone, shale, and conglomerate. Transitional from the Miocene. to the Pleistocene.	Living shells *Mactra* (not *Venus*) *pajarocnsis*. Large *Pectens*, *Arcas*, etc. Cetacean bones.	Thickness 4500 + ft.
Miocene	Monterey Ser.	Bituminous or White Miocene shale; with some sandstone.	Infusoria. *Pecten peckhami*, *Tellina congesta*.	Thickness 1000 ft.
Eocene?	Pescadero Ser.	Sandstones and conglomerates; Carmelo series (?) Pescadero sandstones and shales.	*Turritella hoffmanni*. *Ostrea titan*. *Liropecten estrellanus*. *Dosinia*, etc.	Thickness 2000 to 10,000 ft.?
Cretaceous?		The "San Francisco sandstone" (in part). Aucella beds.	Plant remains. *Inoceramus*. *Aucella*.	Thickness ?
Pre-Cretaceous		Radiolarian chert or phthanite. Metamorphic sandstone. Gavilan limestone.	Radiolaria. Foraminifera.	Thickness ?

It is usually highly crystalline, and, though of great thickness, is not prominent in the mountains.

The granite appears prominently in only two ridges; from Point San Pedro southward a few miles, and from Santa Cruz to Pescadero Creek. Occasional outcrops, however, show that it has considerable body under the main ridge. It is thought to be

younger than the limestone and the other metamorphics. The cherts have been described by Mr. Becker under the name of phthanites,[1] and more recently by Mr. F. Leslie Ransome as radiolarian cherts.[2] They are usually dark brown, thin bedded, much contorted siliceous rocks, very characteristic wherever found in the Coast Ranges. The only fossils thus far found in them are *Radiolaria*, and these have led to the belief that the rocks are of Jurassic or Cretaceous age. In connection with the radiolarian chert there frequently occurs a metamorphic sandstone, ranging in color from light yellow to dark brown. It usually shows evidence of having been subjected to agencies which have obliterated nearly all bedding planes, produced secondary silicification, and frequently reduced the whole to a structureless mass.

In various parts of the range are considerable areas of serpentine and kindred rocks. The origin of this serpentine has been the subject of much discussion. There can now be no doubt but that it is a decomposition product of peridotes and other igneous rocks with which it is associated.

The relation of the metamorphic rocks to each other and to the younger rocks is very obscure, and the subject will not be taken up here.

THE PESCADERO SERIES.

The San Francisco sandstone was one of the earliest formations recognized and described in California. By Professor Blake it was assigned to the Tertiary.[3] It was later found that the fossils upon which his conclusions were principally based came from the Pliocene of the Merced series. Professor Whitney called the formation Cretaceous, classing the metamorphic rocks with it.[4] Recent writers have thought the metamorphics and San Francisco sandstone pre-Cretaceous.[5] The writer has been able to verify Professor Blake's first conclusion. The sandstone

[1] Monograph XIII., U. S. Geol. Sur., 1888.
[2] Univ. of Cal., Bull. Dept. Geol., I., 199–200.
[3] Rep. Geol. Recon. of Cal., 1858, p. 153.
[4] Geol. Surv. of Cal., Geology, I., 77, 24, etc.
[5] American Geologist, IV., March, 1892, 133.

has been traced from outcrop to outcrop from San Francisco, through the San Bruno Mountains to Point San Pedro, and down to Pescadero where there is for about four miles a continuous exposure of the series with a perpendicular dip. At one end of this series were found characteristic Miocene fossils, such as *Turritella hoffmanni*. This clue was then followed back into the mountains to other localities yielding a more abundant fauna from which may be mentioned *Ostrea titan* and *Liropecten estrellanus*.

Having thus shown that a part at least of what has been known as the San Francisco sandstone is of Miocene age, it is believed that most, if not all, of those localities from which *Ostrea titan* and the associated fauna have been reported will be found to show the presence of the Pescadero series.

In Bear Creek Valley near Haakerville fucoids occur in a light-colored sandstone. Mr. Gabb correlates these rocks with what has since been shown to be Tejon (Eocene) in the Monte Diablo region. As the strata near Haakerville are believed to form part of the Pescadero series, some evidence is thus afforded that the Pescadero series is in part of Tejon age.

In the head waters of Stevens' Creek, and in Alum Rock Canyon in the Mount Hamilton Range near San Jose, are found the fossiliferous strata of the Pescadero series.

Lithology and stratigraphy.—The Pescadero rocks may be described under three facies, the first two of which everywhere grade into each other, the last being more distinct.

The first is typically developed at Point San Pedro. The exposure there consists of dark and black shales and shaly sandstones which, while showing finer bedding, are distinctly bedded in layers of one to three inches or more in thickness. These beds weather into soft yellow layers. This facies is well exposed in San Francisco in the deep cut on Second street. The second facies is the sandstone described by Whitney as the San Francisco sandstone; a heavy-bedded sandstone, yellow or brown where weathered, but a dark gray blue where freshly exposed. In places the beds are a foot or two in thickness, and the strati-

fication is distinct. In other places the strata are heavily bedded and frequently so intersected with joint planes that it is difficult to make out the real bedding.

These two facies were not found occupying definite horizons, but, as in the Pescadero section, grade into each other irregularly in the vertical section.

The third facies is more characteristic. It is hard, brown or dark colored conglomerate, heavy bedded, the pebbles of metamorphic rock are from one to four inches in diameter, and are sometimes distinctly faulted.

The Pescadero section gave a questionable thickness of over 10,000 feet. The exposure is cut off on the north by a nonconformity, and on the south by a fault. The conglomerates at the top or south end of the section have a thickness of 720 feet. It is thought that the Carmelo series of Professor Lawson[1] may be only a local development of the conglomeratic facies.

Occurrence.—The Pescadero series is well exposed at Benicia; in the northeastern quarter of San Francisco; in the San Bruno Mountains, and all through the Santa Cruz, Mount Hamilton and Monte Diablo Ranges. It will probably be found to be widespread throughout the Coast Ranges.

Relations.—No evidence of nonconformity between the Pescadero series and the metamorphic sandstone and phthanite was found, although one probably exists. The lowest Eocene and the uppermost Cretaceous are, as yet, unknown in California, and in the southern part of the state Chico beds lie unconformably on Knoxville, showing the absence of Horsetown strata.

THE MONTEREY-MERCED PERIOD.

The Monterey series was long ago described and assigned to the Miocene, and later investigations have not modified that decision.

The Merced series was first mentioned by Whitney, who merely speaks of the finding of Pliocene strata on Seven Mile Beach[2] by Gabb and Remond. Until recently these beds seem

[1] Univ. of Cal., Bull. Dept. Geol., Vol. I., p. 19.

[2] Geol. Surv. of Cal., Geology, I., 79.

to have commanded but little attention. They were recently described more in detail by Professor Lawson, by whom they were called the Merced series.[1] They have been called Pliocene by all who have worked on them. From Half Moon Bay southward at a number of places occur very fossiliferous beds which have often been referred to, but of which very little has been written. The fossils obtained from these beds have been referred by some to the Miocene, by others to the Pliocene. The same beds have been referred to the Pliocene where little disturbed, and to the Miocene where much disturbed.

The field-work of the writer has shown:

1. That, though minor oscillations have occurred, there was continuous sedimentation from the beginning of the Monterey period to the end of the Merced.

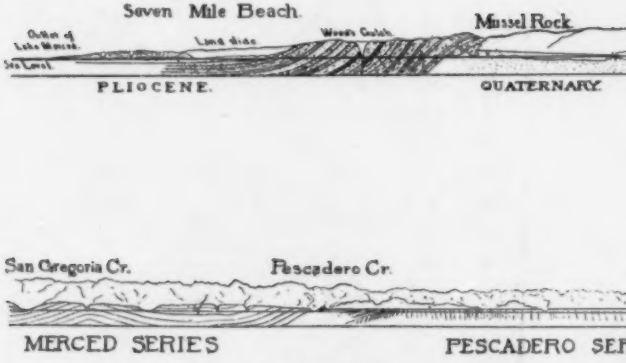
2. That the two series are similar in structure, that structure having been determined by the movement which took place at the end of the Merced period.

3. That the fossiliferous beds south of Half Moon Bay are conformable with the Monterey series below them and with the Merced series above them.

4. That the Monterey series is Miocene; that the Merced series on Seven Mile Beach is principally Pliocene, and that the fossiliferous beds, transitional between the two, contain a mixture of Miocene and Pliocene forms. In other words if a line were drawn between the Miocene and the Pliocene it would not come at the top of the Monterey series, as usually defined, but from one hundred to several hundred feet higher—somewhere in the fossiliferous beds.

It would be difficult, if not impossible, to draw the line between the two ages, as it would be largely governed by individual inclinations. Accordingly the writer prefers simply to call them the Transition beds of the Merced series, grouping them with the Merced series because lithologically they are similar to the predominating rocks of that series.

[1] Univ. of Cal., Bull. Dept. of Geol., I., 143.



Section from San Gregorio to Pigeon Point, 8 miles.

Vertical scale twice the horizontal scale.

Section from Lake Merced to Purissima, 23¼ miles. Vertical scale twice the horizonta

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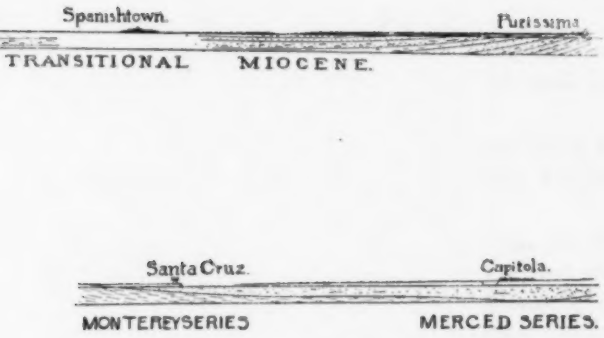
iles.

ed to Purissima, 23¼ miles. Vertical scale twice the horizontal scale.

PLATE IX.



Section from Santa Cruz to Capitola, 5 miles.

Vertical scale twice the horizontal scale.

Lithology.—The Merced series of the Santa Cruz Mountains is composed of a great thickness of partly consolidated sands, clays, argillaceous sands and hard fine conglomerates. The most abundant and characteristic rock is a dark drab or slate-colored argillaceous sand, breaking into small fragments of about half an inch cube, frequently with bright red or yellow faces. It varies in hardness from that which crushes easily in the hand to more argillaceous varieties which are tough like clay. A soft yellow or buff-colored sand is quite common, and along Seven Mile Beach there are many thin layers of hard conglomerate, usually containing many fragments of shells. Occasionally shells are so abundant as to form shell breccia.

Near the top of the section on Seven Mile Beach the strata become more and more unconsolidated and sandy, the upper layers consisting almost entirely of soft yellow and orange-colored sand. Near the top is a soft, white, chalky layer, from one to six feet thick, which Dr. Lawson considers a volcanic ash.[1]

Stratigraphy.—The section along Seven Mile Beach has a thickness of about 4500 feet; it is not complete, however, but is cut off at the bottom and south end by the great fault which runs from Mussel Rock to Black Mountain. The lower or Transition beds are exposed south of Half Moon Bay, but no way of connecting them with the Seven Mile Beach section was found. Near San Gregorio about 500 feet of strata is exposed.

Distribution.—The Merced series, antedating as it does the upheaval which gives the Santa Cruz Mountains its present topographic position, was probably originally laid down over all or most of the region now occupied by these mountains. Pleistocene movements have preserved the lower deposits, while erosion has removed the strata from the upper parts of the range.

It seems possible that most of the beds in different parts of the state from which older Pliocene fossils have been reported will be found to correspond with this series. Dr. Lawson believes that the one he recently described as the "Wild Cat

[1] Univ. of Cal., Bull. Dept. Geol., I., 144.

Series"[1] in Humboldt county may be correlated with the Merced series. Thus the fauna reported from Kirker's Pass and Green Valley, Contra Costa county, Santa Rosa and Russian River, Sonoma county, suggests the presence of the Merced series. The formation is fairly well developed at San Fernando, Los Angeles county.

Relations.—Near Santa Cruz the Merced series overlies conformably the Monterey series; the two formations seem to grade into each other at the contact. At a number of places the Merced series lies directly upon the pre-Monterey formation. This may have been due either to transgression of the sea during the Merced period or to erosion during part of one or during both of these periods.

Structure.—The end of the Monterey-Merced period was followed by the movement which elevated the Santa Cruz Mountains, making them again a prominent topographic feature. This movement was largely of the nature of faulting, and the largest fault noticed was the compound one, beginning at Mussel Rock and extending southeast nearly to Black Mountain. Many small faults were noticed; among these the one at Wood's Gulch on Seven Mile Beach has a displacement of nearly 900 feet. These faults have a strike of about southeast and northwest. Another group has the strike nearly due east and west.

As a rule the structure of the Merced and Monterey series shows only gentle folding, but locally, as on Seven Mile Beach and in that neighborhood, the dip becomes almost vertical. The structure along Seven Mile Beach reveals a great monocline, with the dip to the northeast. The other limb of the monocline is to the south in the long exposure at Pillar Point. Thence southward the structure shows gentle undulations until Pescadero Creek is reached. At Point New Year and at Capitola synclines show the presence of the Transition beds of the Merced series.

Correlation.—The Transition beds were principally noted along the coast from Spanishtown southward; also near Stanford

[1]Univ. of Cal., Bull. Dept. Geol., I., 255.

University, and in the ridge through which is cut the San Fernando tunnel in Los Angeles county.

Fifty-two species of fossils were found in the coast area of which eighteen are not known living, and four are not known in the present fauna of the same region. Using the old method of percentages we find 56 per cent. of the fossil fauna in the living fauna. It is found that twenty-two of the forms have been found in strata whose Miocene age is not questioned, of which number five are strictly Miocene. This would place these strata, according to some authorities, in the lower Pliocene; according to others, in the Upper Miocene. We do not as yet feel safe in asserting the identity of any of these species with those found in the Atlantic Miocene. In many cases, however, the resemblance is so strong that for all practical purposes we may assume them to be of the same type, and use them as though we felt sure of their specific identity.

The strata, like the Atlantic Miocene, are characterized by many huge Pectens, large Arcas, and other forms which have no representatives in the present waters of the coast. Thus, there is on the coast of California one very small species of *Arca*, found at San Diego. In these strata we find great numbers of several species of *Arca*, some of which are over four inches broad. The most common of these, the *Arca microdonta*, Conrad, will fit the figure and description of *Arca arata*, Say, of the Maryland Miocene just as well as it does Conrad's figure and description of the west coast species. The presence of the large Pectens, six or seven inches across, gives the fauna a strong resemblance to the Atlantic Miocene of Virginia and Maryland. Aside from the above localities these Pectens have been previously reported only from strata generally recognized as Miocene. The *Crepidula grandis*, Midd, is another form about four times as large as any of its living representatives. Many other interesting forms might be mentioned. It is thus seen that the fauna, while closely related to the living fauna, as shown by the percentages given above, has quite a number of species closely resembling species which, in eastern America, are typical of the Miocene.

In the area near Stanford University the percentage is still lower; out of twenty-five species found only 44 per cent. belong to the living fauna.

On Seven Mile Beach the great thickness of strata gives a good opportunity for the study of faunal changes. Thus the large *Pectens* are limited to the bottom of the series. Of the forms obtained on Seven Mile Beach, *Neptunea tabulata*, *Calyptræa filosa* and *Crepidula prærupta* occur only at the bottom of the section. *Crepidula grandis*, *Arca microdonta*, *Cardium meekianum*, *Saxidomus gibbosus*, *Mactra* (not *Venus*) *pajaroensis* and *Scutella interlineata* disappear at different horizons in about the order named, and are replaced in the uppermost layers by living forms. Thus, for example, the living *Echinarachnius excentricus* replaces *Scutella interlineata; Cardium corbis* replaces *C. meekianum* from which it probably descended.

Of the forms collected on Seven Mile Beach, not including the uppermost beds, thirty-two species have been identified. Of these nine are not known to be living, and five are found only in some other district. Out of thirty-two species in the fossil fauna this gives eighteen, or 57 per cent., in the present fauna of the same region. The character of the fauna is noticeably southern.

The suggestion has been made that the top of the Merced series on Seven Mile Beach extends into the Pleistocene, the fossiliferous strata above what has been called the "upper gasteropod bed" especially having a Pleistocene aspect, as all the forms found in these are still living on the coast. The whole fauna, including the "upper gasteropod bed," gave 81 per cent. of the fossil fauna living in that region.

Not only does the fauna suggest that these upper beds might be considered by themselves, but the structural relations to the lower beds is just obscure enough to prevent a positive assertion that they are conformable. The first writers on the subject regarded them as conformable.

Dynamic movements during the Tertiary.—At the beginning of the Tertiary all the region about the Bay of San Francisco seems to have been slowly sinking and steadily receiving sediment.

This continued until the Miocene. Then the great thickness of sediment yielded to mountain-forming forces. Geologically speaking this movement seems to have been quite rapid, if we may judge from the thorough way that the rocks have been folded, broken and crushed. For a time subaërial erosion was the principal dynamic factor at work in the area of the mountains. Then a slow subsidence set in, and the white shale of the Monterey series was deposited on the coast side of the mountains. In some places what is now the crest of the mountains was covered by the white shale. Then the sediment became sandy, the old mountains which had meanwhile been much eroded settled still more, and the Merced series was laid down. Near San Francisco the conditions were favorable for rapid sedimentation, and nearly a mile of thickness was laid down. Finally at the end of the Pliocene, or beginning of the Pleistocene, movement began along the old axis. Great faults were formed and the center of the range rose, not to its present height, but to a position probably about 1000–1200 feet lower. This left the present flanks of the mountains under water, a fact which doubtless accounts for the preservation there of the soft Merced series.

II. THE PLEISTOCENE HISTORY OF SAN FRANCISCO PENINSULA.

Topography.—The main portion of San Francisco peninsula is occupied by the northern end of the Santa Cruz Mountains and their foothills. The strike of these mountains to the northwest carries them to the seaboard a few miles south of the Golden Gate. In the southern part of the peninsula the mountains are separated from the bay by a broad plain. At the northern end this plain, narrowed down to a valley or windgap of some breadth, separates the mountains from the San Bruno Mountains, a parallel range only a few miles long, and from the irregular groups of hills in the city of San Francisco. On the ocean side of the mountains are remnants of a similar plain. These plains on both sides of the mountains are one of the most marked features of the topography. They usually start quite abruptly from the

steeply sloping foothills, at levels varying from 100 to 200 feet above sea level and slope gently toward the bay or sea. On the bay side these extend to the water's edge, and then are continued without change of grade to the center of the bay, then rise as slowly on the other side. On the ocean side wave action has generally cut away the lower part of the slope, leaving cliffs from ten to one hundred feet in height.

Where the contact between this level stretch and the foothills is not parallel with the shore-line or main axis of the mountains it is noticed that the elevation of the contact rises toward the axis of the mountains. In some cases this level seems to be carried up small streams nearly, if not quite, to their heads, forming a marked bench on either bank down through which the streams have recently cut. As some question has been raised as to whether these terraces are not the results of erosion rather than of sedimentation, it may be well to call attention to the evidence more in detail. In the first place, these terraces and fillings show only horizontal bedding; further, the bedding of the strata forming the hillsides is in nearly every case more or less highly inclined; and, finally, in nearly every ravine one or more contacts were found where the horizontal strata can be clearly seen lying upon the highly inclined strata of the Merced series. A few of these might be mentioned. In the head of Wood's Gulch and in the ravine which heads near it a few yards below the Old San Pedro-Colma road, the Merced sandstones and thin-bedded gravels have an almost perpendicular dip. On the edges of these perpendicular beds lie the horizontal Quaternary strata, which may be traced continuously down the ravine to a point near the crossing of the New San Pedro-Colma road; here are found many horizontal pines imbedded in the strata. In the cut just north of the Happy Valley House the horizontal Pleistocene overlies strata of the Merced series, having a dip of 35° N. 20° E.

A study of the neighborhood of San Francisco Bay points to a recent elevation of the mountains to a level much higher than their present. Such a study, as recently pointed out by Professor

Lawson,[1] shows the strong resemblance of San Francisco Bay, of Rodeo Lagoon, Tomales Bay, Walker's Creek, Drake's Bay, Ballenas Bay, the Valley of Lake Merced, etc., to sunken and submerged valleys.

There is another topographic feature which must not be overlooked. Standing upon the hills near South San Francisco station where a comprehensive view can be obtained of the line of hills extending from Seven Mile Beach to Redwood City, their summits can be seen to present a remarkably even horizontal line. Examined on the ground the top of this line of hills has the aspect of a dissected plateau, from which rise a few sharply conical knobs. These have the appearance of remnants left by the eroding waters which planed off the top of the hills.

Dr. Lawson has also pointed out that the whole coast has recently stood for a considerable time at an elevation of 1600 to 2100 feet below its present level.[2] Evidence of this is seen in the level summit of the main ridge to the north of Black Mountains.

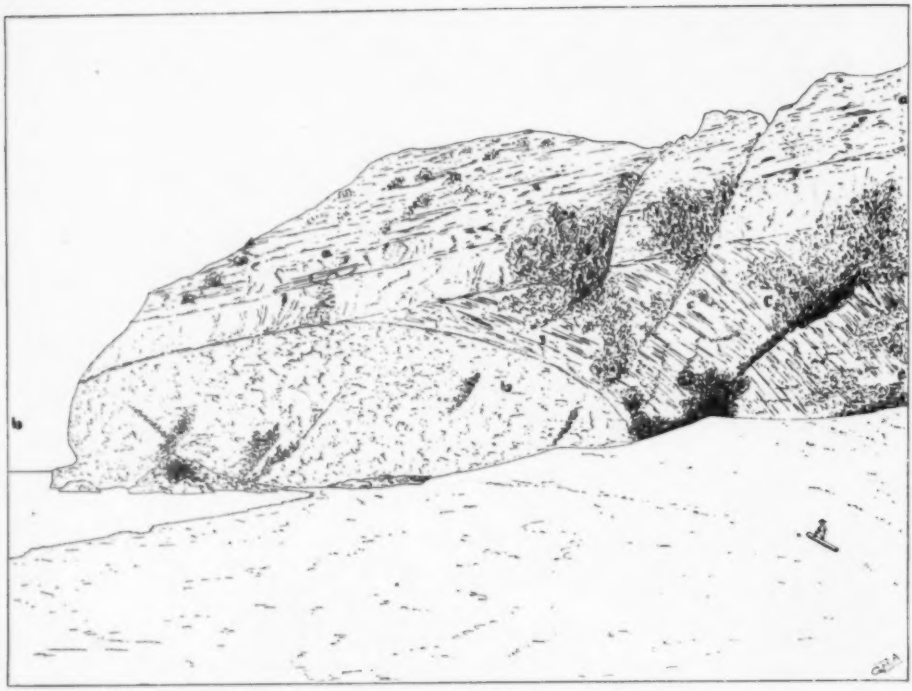
The deposits.—Turning to the deposits we find three distinct sets exclusive of those now forming.

Of the first only remnants remain. They are the deposits corresponding with the topographic features last mentioned. All along the level summit of the foothills no deposits are noticed until Black Mountain is approached; then the summits of the foothills are more or less covered with water-worn bowlders of metamorphic rocks. Bowlders do not occur further north, probably because in that direction the foothills are separated from the main ridge of the mountains by the long deep valleys of Bear Creek, Crystal Springs, and San Andreas, while near Black Mountain the foothills are connected with the mountains which must have supplied all such material.

The second class of deposits are stream and wind deposits. These are quite prominent in the benches in the streams. They appear as sand dunes on the ocean side of the mountains buried

[1] Univ. of Cal., Bull. Dept. of Geol., I., 263.

[2] Univ. of Cal., Bull. Dept. Geol., I., 115–160.



Mussel Rock from the South, showing marine Pleistocene (*a*), overlying sand dunes (*c*), and igneous rocks (*b*).

below marine deposits of later date. (See Plate X.) They make up a considerable portion of the level plain surrounding the bay as shown by recent stream cuttings. These deposits have yielded remains of the mammoth or mastodon, and in the deposits in the various streams running to the bay are found a large number of trunks and cones of conifers, sometimes four feet in diameter.

The third class are recent marine deposits. On the ocean side these are very marked, forming the top of the level benches described and having a thickness in the sea-cliffs of from five to fifty feet, in one place just south of Mussel Rock, having a thickness of over 200 feet. In some places, as near Monterey lighthouse, the beds are only a foot or two thick, and are made up of black earth, rocks, and abalone shells in great numbers. On the bay side of the mountains the surface of the broad valley plain and stream benches is the result of marine erosion and deposition. The deposits there are seldom more than a foot or two thick. Here are also found large areas of black earth full of rocks and shells.

History.—The interpretation of these data would seem to be as follows:

1. A period of erosion with the mountains about 1800 feet below their present level. This may have been the final position of the mountains at the end of the post-Merced movement, or the mountains may have shifted to this position soon after. During this time the most of the soft Merced series above the water line seems to have been removed, the water acting as a protection to the deposits which now fringe the base of the mountains.

2. A period during which the mountains stood about 1200 feet higher than during the first period, or about 600 feet below their present level. This produced the marked bench or plateau forming the summit of the foothills.

3. A period during which the region stood, according to Professor Lawson,[1] nearly 400 feet higher than at present. San Francisco Bay was a broad valley and the islands stood up as

[1] Univ. of Cal., Bull. Dept. of Geol., I., 267.

prominent hills. Conifers were abundant over parts of the area now treeless.

4. A period of subsidence. Tide-water entered the Golden Gate, filled San Francisco Bay, then spread out over the Santa Clara valley to the foothills. The whole region to the foothills was reduced by erosion and deposition to a level. The waters extended up many of the streams. San Francisco was a little cluster of islands. Considerable deposits were laid down upon the ocean-side of the peninsula.

5. A period of uplift to present level. One of the most interesting features of the last period is the remarkable erosion which has taken place in the deposits laid down in the periods just preceding. The topographic changes caused by erosion in the last twenty-five years have been so marked that, judging by the evidence of erosion in these latest beds previous to 1869, we must conclude, either that these beds have been subjected to erosion a very short time or that climatic or other conditions have become more favorable for erosion of later years. Quite a large number of hollows through which ran in 1869 county or farm roads now present impassable gullies, twenty-five to seventy-five feet deep.

III. THE AGE OF THE COAST RANGES.

A casual examination of a topographic map of California reveals a lack of unity between the northern and southern Coast Ranges as regards their strike and the apparent direction of folding. The ranges occupying the coastal region of central California have a very uniform strike of northwest and southeast, suggesting a certain unity in the time and manner of their uplift. In Santa Barbara County we come abruptly upon a series of ranges running nearly east and west through Santa Barbara, Ventura and Los Angeles counties. These ranges seem to possess a certain unity in having been elevated together. Was the movement synchronous with the elevation of the ranges further north? A comparative study of one of the ranges of each group can hardly be taken as conclusive of the groups of

ranges as a whole, but will be suggestive of what may be true of all.

The age of the Santa Cruz Mountains can with little question be placed at the end of the Merced period. Unfortunately, we are not as yet able to say exactly what is the age of the topmost beds of the Merced series. The highest beds from which fossils were obtained gave a small fauna, all of whose forms are living on the coast today, thus seeming to be of Pleistocene age. Including the fossiliferous beds which occur a few feet further down, and which must be included with the top beds, the fossil fauna shows 81 per cent. of living forms, thus seeming to be of Pliocene age. The most that can be said is that the post-Merced uplift occurred just about the end of the Pliocene or early in the Pleistocene. In either case these Coast Ranges of California are among the youngest mountain ranges of any prominence in the world.

Turning to the San Fernando Range, we find the topmost beds concerned in the uplift and folding of the range correspond with the lower or transitional beds of the Merced period, thus placing their age about the end of the Miocene or beginning of the Pliocene.

Further confirmation of this is found in a study of the horizontal fossiliferous deposits along the coast, as at Santa Barbara, San Pedro, San Diego, etc. Thus, at San Pedro in Los Angeles county, there is found first the shales of the Monterey series dipping south. Above them unconformably come first a little sand dune or wind deposit, then a few feet of quite fossiliferous sand, then a top fossiliferous layer.

The top layer is unquestionably Pleistocene. A study was made of the fossiliferous layer just below. Altogether 125–150 species were collected in this layer, of which number 104 species have been determined. Of the 104 species identified 99 or 95 per cent. are known living. But many of those living are only known now in, for example, the Arctic fauna. Thus it is found that of the 104 species twenty-six have not been reported from the coast near San Pedro, leaving seventy-eight species of 104 fossil species known to be living, or 75 per cent.

Again it is noticed that of the species which have migrated all but two have gone northward, a number being known only in Arctic waters at present.

A percentage comparison of the fauna of these beds with the present fauna of that part of the coast would make the beds Pliocene. A consideration of the Arctic character of the fauna would place them near the end of the Pliocene or the beginning of the Pleistocene. In any case they probably do not differ greatly in age from the beds which form the top of the Merced series in the Santa Cruz Mountains.

If these observations and their interpretations have been correct this will make the age of the east and west ranges of Santa Barbara, Ventura, and Los Angeles counties near the beginning of the Merced period or about the end of the Miocene; while the ranges to the north were elevated at the end of the Merced period or near the end of the Pliocene.

IV. ON THE RECENT HISTORY OF SANTA CATALINA ISLAND.

The finding of a species living which had been supposed to be extinct, or which if not extinct had long since been forced by changing conditions to migrate to some other region, has always had a peculiar interest to the student of biology or geology. Still more interest attaches to the finding of a fauna which belonged to a bygone age, and especially when the record of events is sufficiently clear to give a plausible reason for the presence of the older fauna. Such a condition of things seems to exist on Santa Catalina Island today.

In the preceding study attention was called to the existence at San Pedro, and other points, of beds containing an abundant fossil fauna of probably Pliocene age. The two fossiliferous beds at San Pedro were deposited during a submergence of all the coastal region, the lower or Pliocene beds having preceded the submergence, the upper beds having been laid near the end of the elevation which followed. This movement shows most clearly in the topographic features of the coastal region of southern California. Everywhere near the coast is evidence of a

recent submergence to a depth of from 1200 to 1500 feet. The long stretches of plains and level benches, the old cliffs marking the advance of wave action, the stream topography which within those levels seems to be just taking a new start, are all evidence of the same fact.

Santa Catalina Island is a large island lying about twenty miles south of San Pedro. A short time since Professor Lawson called attention to the fact that Santa Catalina Island had not shared in the general depression which had submerged the other islands and coastal regions.[1] He pointed out that the island shows no shore lines, no benches, no levels of erosion. The stream basins are all of considerable age, having deep, rugged valleys, and the sharp edges of the separating ridges are typical of subaërial erosion long continued.

We find, then, that the conditions have remained constant here since the time when the Pliocene beds were being deposited over on the mainland. It will be of interest then to compare the present fauna of Santa Catalina Island with the fauna living now on the coast of San Pedro, and also with the fossil fauna found at the same place.

By a study of Dr. Cooper's list of Californian fossils, 1888, we find that five otherwise extinct species from the Pliocene or Quaternary of Santa Barbara, San Pedro, and San Diego are still living on the island: *Amycla undata*, Carpenter; *Daphnella clathrata*, Gabb; *Nassa insculpta*, Carpenter; *Psephis salmonea*, Carpenter; *Solarellia peramabilis*, Carpenter. There are also found living on the island, and fossil on the mainland, one species, *Cryptodon flexuosus*, Montagu, known elsewhere only in the North Atlantic; one, *Lucina borealis*, Linnaeus, known elsewhere only in Arctic waters; one, *Laqueus californicus*, Koch, known elsewhere only in the North Pacific. In addition to these, thirteen species—*Bittium asperum*, Gabb; *Callista newcombiana*, Gabb; *Cardium centifilosum*, Carpenter; *Chrysodomus tabulatus*, Baird; *Diala acuta*, Carpenter; *Leptothyra bacula*, Carpenter; *Lucina trunisculpta*, Carpenter; *Lunatia pallida*, Broderip and Sowerby;

[1] Univ. of Cal., Bull. Dept. Geol., I., 138.

Margarita pupilla, Gould—which are found on or about Santa Catalina Island are only known elsewhere on the coast to the north; while it forms the northern limit of four species, *Chorus belcheri*, Hinds; *Nucula exigua*, Sowerby; *Omphalius fuscescens*, Philippi; *Ostrea conchaphila*, Carpenter.

These facts indicate that fauna of Catalina Island has been little affected during a time when many species on the mainland have become extinct and others forced to migrate. The fauna is largely northern, though possessing a few southern forms. It thus resembles quite strongly the fauna studied at San Pedro and called in this paper Pliocene.

This case is interesting, not alone from showing that the fauna considered Pliocene on the coast of the mainland is still living on or about the island, but from the way the deductions made from the topography and from the fauna support each other.

GEORGE H. ASHLEY.

STOCKTON, CAL.,
April 6, 1895.

SOME CRETACEOUS BEDS OF ROGUE RIVER VALLEY OREGON.

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INTRODUCTION.

In the summer of 1894 a large part of the months of June and July was spent by the writer in studying the Cretaceous beds of southern Oregon.[1] The deposits most thoroughly worked lie in the portion of Rogue River Valley west and southwest of Jacksonville, extending to the summit of the Siskiyous where these are crossed by the Oregon and California Railway. This region is more strictly an arm of what is commonly known as Rogue River Valley, and may, for the purpose of the present paper, better be called the Bear Creek Valley. Its general direction is northwest and southeast. It lies between the high granitic ridges of the Siskiyous on the southwest and the southern portion of the Cascade range on the east. The upper portion of the valley, near where the railway crosses the summit, is not far from the point where the Siskiyous join the Cascades. From this point the valley widens gracefully into the deep basin,

[1] The data obtained were studied at the laboratory of Stanford University, where much of the material collected is preserved.

into which one may look down from the cars when near the little station of Siskiyou. Two or three miles below the town of Ashland some granitic ridges from the south come down abruptly to the creek, almost severing this upper portion of the valley from the main valley beyond. West and northwest of these ridges the valley expands again until, in the vicinity of Medford, its width is from eight to ten miles, while from this point to the summit just mentioned the distance is something like twenty-five miles. In this valley the Cretaceous beds appear mainly on the eastern side, or on the side east of Bear Creek, and probably also occupy the floor of the valley where they are overlain by Pleistocene deposits.

It has been thought that these beds, which are of Upper Cretaceous or Chico age, extend indefinitely eastward under the lavas of the Cascades.[1] It cannot be said, however, that the facts observed during this study confirm this opinion. On the contrary, the true relation of the sedimentary rocks here described to the rocks of the Cascades is so apparent and so uniform that one cannot fail to be convinced that at least this portion of the Cascade range is older than the Chico portion of the Cretaceous.

PRE-CRETACEOUS.

Underlying the Cretaceous are three distinct series of rocks which may be called the granite series (including the schists), the basalt series and the slate series. The point of junction between these series is probably not far from the town of Talent; and from this point lines separating approximately the three pre-Cretaceous series may be drawn as follows: Toward the southeast the general course of Bear Creek, or, still better, an irregular line between that and the line of the railway divides the granite on the west from the basalt on the east; toward the southwest the line separating the granite on the south from the slates on the northwest follows the course of Wagner Creek southward for a mile or more, then swings toward the west and

[1] Geol. Sur. Cal., Vol. I., p. 354. Seventh An. Rep. U. S. Geol. Sur., p. 98. U. S. Geol. Sur., Bull. 33, p. 20.

follows the upper portion of Anderson Creek to its head; from Talent the line between the slates on the west, and the basalt on the east, runs in a northerly direction.

Each region and each series has its own distinguishing characteristics. The rocks of the granite series are made up of massive granites and of folded and contorted schists. No attempt was made to separate these in working out the areal geology. The peaks and ridges of this area are high and rugged, and the canyons are deep and generally heavily timbered with spruce and pine.

The slates, which are no doubt a northward continuation of the auriferous slates of California, portions of which they closely resemble, are variable in character. In some places they are dark, fine grained and argillaceous; in other places they are micaceous, talcose or shaley with large masses of quartzite. Where they are auriferous they often contain numerous small and irregular veins of quartz. The mountains of the slate area are less rugged, often low and less heavily timbered than those of the granite area.

The area of basaltic rocks is also well characterized by regular and rolling hills which are generally not deeply eroded, and in which the rocks seem to be more uniform. These basaltic hills form the western edge of the Cascade range at this point. For the most part they consist of old basalts, andesites and other basic eruptives.[1]

Upon each of these series of rocks the Cretaceous strata rest with equal distinctness, and with equal absence of metamorphism, or alteration, other than what would be expected from weathering. The only case of alteration that was observed in these rocks is in the immediate vicinity of dikes of limited extent, which have made their way through the strata at various places, often without disturbing the regular position of the beds. In such cases the alteration is confined to a few feet or yards on each side of the intruding mass. As far as is known the dikes occur mostly along the line of junction between the granite and the basalt.

[1] Seventh An. Rep. U. S. Geol. Sur., p. 98.

CRETACEOUS.

Transgression.—It has been pointed out by Mr. J. S. Diller[1] that in the region of northern California and southern Oregon, during the deposition of the Cretaceous strata, a gradual subsidence of the land carried the eastern shore-line inland. In California this transgression of the sea was toward the northeast, while in southern Oregon it was generally toward the southeast. The facts observed in that portion of Rogue River Valley under discussion may conform to this rule in the main, but being in the more immediate neighborhood of the Siskiyous, they may indicate, also, a subsequent elevation of this range relative to the Cascades. The strata consist of heavy beds of conglomerates, shales, and sandstones which generally dip toward the northeast at an angle varying from 10° to 30°.

The fauna of the Cretaceous at Riddles, Douglas county, Oregon, which is about sixty miles to the northwest, shows a much lower horizon for those beds than is indicated by any fossils yet found in this valley. Deposition was therefore going on at Riddles before the Rogue River Valley was submerged.

STRATIGRAPHY OF THE CRETACEOUS.

As the strata generally dip toward the north, away from the granites of the Siskiyous, as shown by the accompanying sections, the lower and older strata appear along the western flank of the valley. However, for the most part the strata are destitute of fossils. This remark applies to the upper beds which occupy the eastern side of the valley, but which, from their lithology, dip, etc., are known to be conformable and continuous with the fossiliferous beds to the west. They are probably equivalent to the barren Chico beds of northern California. Thus far fossils have been found only along the western side of the valley; though along this side, from the summit where the railway crosses, northwestwardly to Jacksonville, fossils are rather abundant. Three localities, besides the two mentioned by Gabb, have furnished fossils of a varied and interesting character.

[1] Bull. Geol. Soc. Am., V., 452.

Ashland locality.—About four miles south of Ashland, near the railway, the following species have been collected:

Pachydiscus aff. denisonianum, Stol.	Cucullæa truncata, Gabb.
Cinulia obliqua, Gabb.	Chione varians, Gabb.
Fasciolaria rigida, Bailey.	Cyprimeria lens, Gabb.
Gyrodes pansus, Stol.	Homomya concentrica, Gabb.
Pugnellus manubriatus, Gabb.	

This indicates an upper horizon for these beds, but not the uppermost Chico. The beds here are of a grayish, or light-colored sandstone, dipping toward the east at an angle of about 30°. A short distance to the south, where the sandstone is quarried on the east side of the railway, the beds are thicker and of a light grayish color; they also dip toward the east at about the same angle.

Griffin Creek.—Collections made at a second locality on Griffin Creek. a few miles east of Jacksonville, contain the following species:

Trigonia leana, Gabb.	Exogyra, sp.
T. tryoniana, Gabb (?).	Inoceramus, sp.

Here the beds are of a tawny or grayish sandstone, and dip at an angle of 20° toward the west and northwest. These strata, as at Jacksonville, a few miles to the west, rest upon the highly tilted or folded auriferous slates. The fossils indicate a horizon a very little lower than the beds near Ashland.

'49–Mines.—A third locality, at which the largest and most interesting collection was made, is one and one-half miles southwest of the town of Phœnix, at the old placer mines, locally known as the '49-Mines. Here also the Cretaceous beds consist of conglomerates, yellow shales, and sandstones, resting upon the auriferous slates and dipping toward the northeast at an angle of 30°. The fossils collected at this point show these beds to be somewhat lower than those before mentioned, although some of the fossils belong to the upper Chico of the California Cretaceous. The following is a list of the fossils identified from this locality:

Acanthoceras, aff. naviculare, Mant.
Pachydiscus, aff. denisonianus, Stol.
Gaudryceras, aff. timotheanum, Mayor.
Lytoceras, conf. jukesi (Sharpe)—— Whiteaves.
Phylloceras ramosum, Meek.
Scaphites, sp. a.
Scaphites, sp. b.
Schloenbachia chicoensis (Trask) Gabb
Schloenbachia inflata, Sow.
Schloenbachia propinqua, Stol.
Schloenbachia, conf. serrato-carinata, Stol.
Schloenbachia, sp.
Nautilus, aff. rota, Blanford.
Baculites, sp.
Hamites, sp.
Heteroceras, sp.
Actæonina californica, Gabb.
Anchura californica, Gabb.
Anchura falciformis, Gabb.
Cinulia obliqua, Gabb.
Cinulia, sp.
Dentalium stramineum, Gabb.
Euspira, aff. pagoda, Forbes.
Fulgur hilgardi, White.
Fulguraria gabbi, White.
Globichoncha remondi, Gabb.
Gyrodes conradiana, Gabb.
Gyrodes pansus, Stol.
Gyrodes, sp.
Margaritella globosa, Gabb.
Avicula nitida, Forbes.
Cardium remondianum, Gabb.
Chione varians, Gabb.
Cucullæa truncata, Gabb.
Cyprimeria lens, Gabb.
Exogyra, sp.
Exogyra, sp.
Homomya concentrica, Gabb.
Inoceramus labiatus, Schloth.
Inoceramus, sp. a.
Inoceramus, sp. b.
Meretrix nitida, Gabb.
Modiola siskiyouensis, Gabb.
Ostrea, sp.
Pectunculus veatchi, Gabb.
Pectunculus sagittata (?), Gabb.
Pinna breweri, Gabb.
Tellina parilis, Gabb.
Teredo, sp.
Trigonia evansana, Meek.

STRUCTURE.

Sections.—The section shown in Fig. 1 is approximately in the direction of the dip drawn through the vicinity of the '49-Mines in a northeasterly direction. Toward the western end, as has been said, the Cretaceous strata rest directly upon the auriferous slates, and dip more nearly toward the north, at an angle of 30°. In the bottom of the valley they are covered by Pleistocene deposits, but appear again where the erosion of Bear Creek has exposed them. From this point, one travels across the upturned edges of the beds to near the summit of the mountain. The dip is pretty uniform for the greater part of the section, but toward the eastern end it is somewhat less steep.

Just east of Bear Creek the first low range of hills is formed

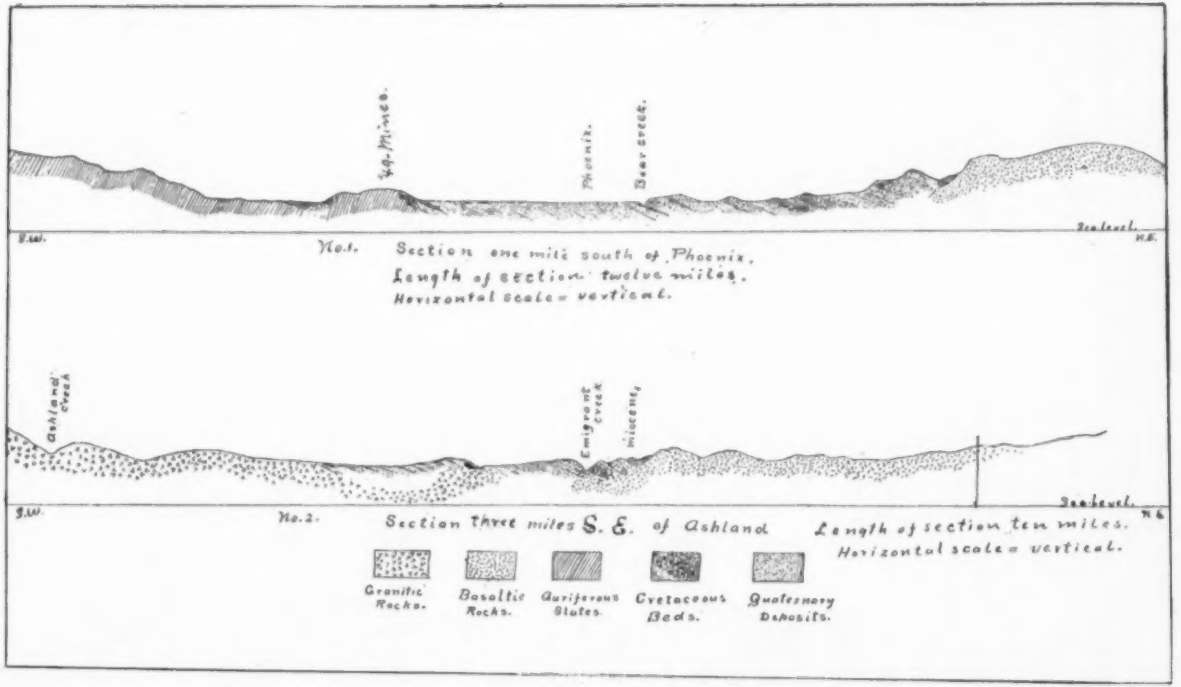
mainly of a coarse pebbly conglomerate, the material of which is of doubtful origin, many of the larger pebbles being quartzose and much worn and rounded. These are succeeded by soft, yellow shales, with sandy layers, and these again by pebbly sandstone, until near the eastern extremity of the section where the strata consist of more massive sandstone with a somewhat gentler dip. These sandstones rest directly upon the old eruptives that form this spur of the Cascades. The contact, which is distinct in numerous places, shows no signs of alteration in the sandstone resulting from their contact with the lavas, nor are the lavas anywhere found resting upon the Cretaceous rocks.

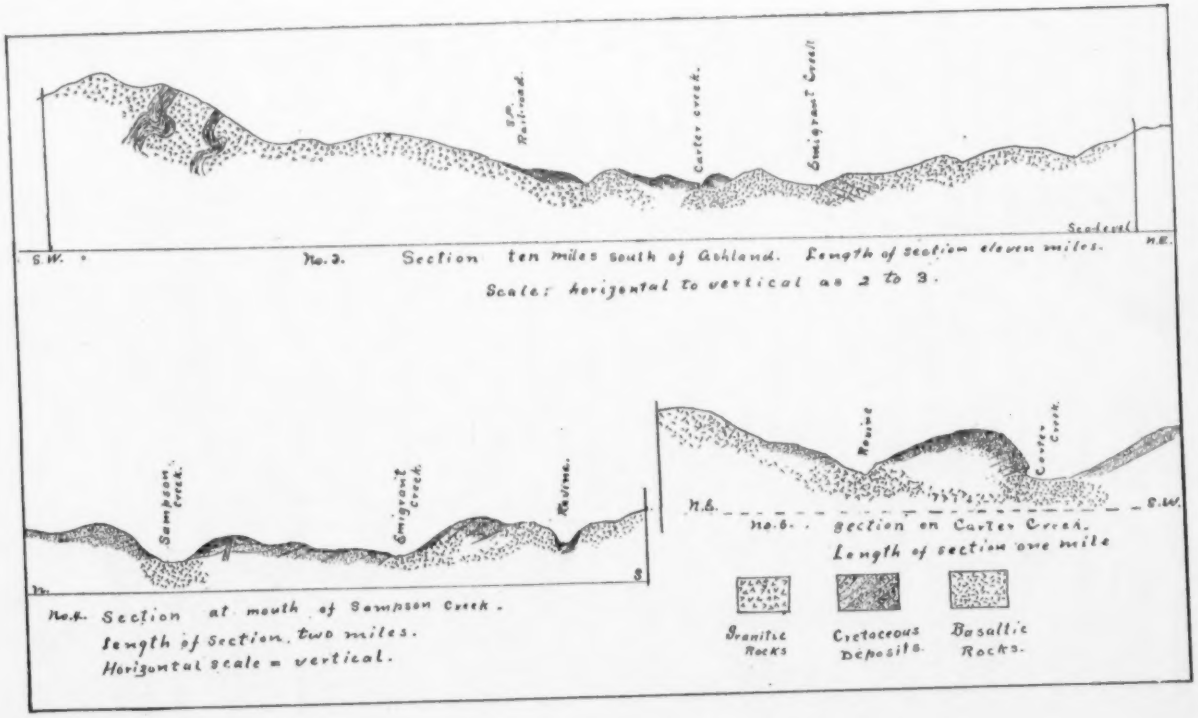
Figure 2 shows a section drawn in a northeasterly direction through the locality at which fossils were found four miles south of Ashland. This locality is at the western extremity of this section. Here the Cretaceous beds rest upon the granite of the adjoining ridge from which they dip away at an angle of 30°.

In the bottom of the valley the granite again emerges from beneath the sedimentary rocks, and is replaced at Emigrant Creek by the pre-Cretaceous lavas upon which the Cretaceous strata rest along the sides of the mountain. Farther up the mountain toward the east the lavas again make their appearance, and continue toward the summit without interruption; but a few hundred yards above the limit of the Cretaceous beds they (the lavas) are covered for a short distance by a remnant of white Miocene shale, apparently of fresh-water origin. These shales contain an abundance of fossil plants, some species of which were identified by F. H. Knowlton, as follows:

Myrica langeana (?), Heer.	Alnus corralina, Lx.
Sequoia langsdorfii, Brgt.	Quercus lonchitis, Ung.
Lastræa fischeri, Heer.	Quercus n. sp.
Planera, sp.	Andromeda, sp.

Still farther toward the south, in the vicinity of Wagner's Soda Springs, the Cretaceous beds have the same general dip of 30° to the northeast and bear the same relation to the granite on the west and to the old eruptions on the east (see section in Fig. 3). Toward the western end of the section the


Ag. Mines.
Phoenix.
Bear creek.
Sea level.
S.W.
N.E.
No.1. Section one mile south of Phoenix.
Length of section twelve miles.
Horizontal scale = vertical.
Ashland creek
Emigrant creek
Miocene.
Sea level.
S.W.
N.E.
No.2. Section three miles S. E. of Ashland.
Length of section ten miles.
Horizontal scale = vertical.
Granitic Rocks.
Basaltic Rocks.
Auriferous Slates.
Cretaceous Beds.
Quaternary Deposits.


S.P. Railroad.
Carter creek.
Emigrant Creek
Scadevil
S.W.
N.E.
No. 3. Section ten miles south of Ashland. Length of section eleven miles.
Scale: horizontal to vertical as 2 to 3.
Sampson creek.
Emigrant creek.
Ravine.
N.
S.
No. 4. Section at mouth of Sampson Creek.
Length of Section. two miles.
Horizontal scale = vertical.
Ravine
Carter creek
N.E.
S.W.
No. 6. Section on Carter Creek.
Length of section one mile
Granitic Rocks
Cretaceous Deposits
Basaltic Rocks.

Cretaceous sandstone rests directly upon and covers the granite, which, however, makes its appearance again in the bottom of a deep ravine a few hundred yards to the east. The basic rocks come to the surface almost in contact with the granite and continue to the summit of the low ridge eastward, where they are covered by the Cretaceous sandstones. These sandstones extend from this point for a distance of a mile or more; beneath them the igneous rocks again appear in the canyon of Carter Creek. From this place they continue eastward indefinitely.

Figures 4 and 5 represent, on a larger scale, some sections at points in the vicinity of Wagner's Soda Springs.

Figure 4 is a north-south section across Sampson Creek a short distance from its mouth. The sides of the canyon are of Cretaceous sandstone, which has been eroded by the stream down to the older basic rocks which here underlie it.

Figure 5 is a northeast-southwest section across Carter Creek one mile north of Smith's Soda Springs. In the bed and on both banks of the creek the rocks are the basic eruptives which, at twenty feet from the stream, on the east bank, show clearly their contact with the sandstones which project over them. These sandstones form the whole of the ridge toward the east, until, in the bottom of the next ravine, half a mile to the northeast, the older lavas again make their appearance.

Thickness of the beds.—It is not easy to say what the original thickness of these beds has been, but the estimated thickness of those remaining is between ten thousand and fifteen thousand feet.

Coal beds.—At various places along the eastern side of the valley small beds of coal are occasionally found. They are the mere remnants of beds once more extensive; they are thin and of no economic importance.

Faults.—Although in some of the accompanying sections there is a suggestion of faulting along the line of Bear Creek, there is no evidence that this is the case. The strata have a uniform dip on both sides of the valley, and those found along the western side are nowhere represented on the eastern. No fossils

except plants have been found east of Bear Creek. The sedimentation was apparently continuous, and the beds are unbroken along the whole length of the section.

Subsidence.—As far as is known all the beds of this region are of younger age than those at Riddles, Douglas county, farther to the northwest, which have been described by Mr. Diller and Mr. Stanton,[1] and which seem to be of Upper Knoxville age. This, as they have shown, indicates a general subsidence of the land toward the southeast.

Elevation.—Glancing again at the accompanying sections, it seems remarkable that the steep and uniform dip of the strata can be accounted for by a subsidence of the land along the eastern shore-line. On the flanks of the Siskiyous, notably near the railway tunnel at the summit, at an elevation of 4000 feet, fossils are found which indicate a lower horizon than that of the barren sandstones upon the basaltic area a few miles to the northeast, at a much lower elevation. The Miocene strata known in this region also dip at a high angle away from the granite of the Siskiyous, which would not be expected without some movement subsequent to their deposition. This elevation, then, probably took place about the time of the general outpouring of the lava which covers eastern Oregon from the Columbia River south, and northern California. This lava, as has been shown by Professor Le Conte and others, is later than the Miocene.[2]

NOTES ON THE FOSSILS.

Horizon.—Although the fossils collected near Phœnix were all obtained from an area of less than one hundred feet square, it is not clear that they are all from the same horizon. A glance at the section, Fig. 1, will show that an immense thickness of strata has been removed at the locality at which the fossils were found. The fossils may not all have been in their original places, as they were found mainly in blocks of hard rock resting irregularly upon

[1] Bull. Geol. Soc. Am., V., 452.

[2] Am. Jour. Sci., VII., 1874, 176. Geol. Sur. Cal., I., 354. U. S. Geol. Sur. Bull., No. 33, 20.

a stratum of softer, yellow shale. These blocks are probably the remnants of overlying strata which have been removed. Many of the fossils, hitherto not cited from this coast, were submitted to Mr. T. W. Stanton, to whom the writer is indebted for many valuable suggestions.

Acanthoceras, conf. *naviculare*, Mant.; Geol. of Sussex, 198, t. 22; Min. Conch, p. 105, t. 555; Cret. Ceph. Ind., p. 73, pl. 39.

Two specimens of this shell were collected and, although not perfect, there can be little doubt that it is closely related to *A. navicularis*. It agrees remarkably well with Blanford's description and figure, and also the description and figure by Sharpe, with the exception of the tubercles at the umbilical end of the longer costæ. Blanford, however, remarks that these are not always present even in young specimens, in which they are usually more constant. The sutures, as far as they can be traced, leave little room to doubt the identity of this species.

Pacydiscus, aff. *denisonianus*, Stol.; Cret. Ceph. Ind., p. 133, pl. 66.

Three specimens of this ammonite were found, one of which is in good state of preservation. The only essential differences that can be seen between this shell and those described from the Cretaceous of southern India is in the slightly greater thickness, and a little wider umbilicus in older specimens of the Indian species.

Gaudryceras, sp.

Four specimens were obtained in good state of preservation, two of which are nearly two inches in diameter. While in some respects this shell resembles *G. timotheanum*, Mayor, the whorls are more rounded and not so thick. One of the smaller specimens and a fragment of another show the squarish whorls, but all of them lack the transverse furrows.

Lytoceras, conf. *jukesi?* (Sharpe), Whiteaves; Pal. Sus., V. 8, p. 53, pl. 23; Can. Mess. Foss., Vol. I., Part 2, p. 111, pl. 13.

A single, well-preserved specimen of this fossil, about one inch in diameter, was found. It agrees fairly well with Whiteaves' description referred to above, with the exception of the trans-

verse ridges. There are, however, slight markings that indicate a periodical interruption of growth.

Schloenbachia chicoensis (*?*), (Trask), Gabb; Proc. Cal. Acad. Sci., 1856, Vol. I., p. 92, pl. 2; Cal. Pal., Vol. I., p. 68, pls. 13 and 14.

A number of specimens were collected of a species closely resembling *A. chicoensis* figured by Gabb, as do also most of the specimens that I have seen from California. It is, however, doubtful if these and Dr. Trask's figures represent the same species.

Schloenbachia inflata, Sow; Min. Conch., II., 1878; Cret. Ceph. Ind., 48, pl. 28 and 29; Can. Mess. Foss., VII., I., part 3, 200.

One specimen five inches in diameter in fair state of preservation, and a large number of smaller ones of this species, varying from one-half to one and one-half inches in diameter, were obtained. The smaller ones are all well preserved.

Schloenbachia propinqua, Stol.; Cret. Ceph. Ind., 53, pl. 31; Can. Mess. Foss., II., Part 3, 247, pl. 33.

One specimen two inches in diameter and a large number of smaller ones, one-half to three-fourths inch in diameter, with numerous fragments of various sizes, all in good preservation, were collected. This fossil, with its numerous bifurcating ribs, tubercles, rounded outer margin, undoubtedly represents the species to which it is here assigned.

Schloenbachia, conf. *serrato-carinata*, Stol.; Cret. Ceph. Ind., 57, pl. 32.

A number of fossils, one-half to one and one-half inches in diameter were collected, which seem to be of this species. In most respects they agree quite well with Stoliczka's figure, but seem to be less deeply grooved along each side of the keel; yet he remarks that the grooves are not so deep as figured. In the specimens collected the keel is prominent, and in some of the specimens serrated, while in others it is not. A double row of tubercles near the outer margin ornament the ribs.

Nautilus, conf. *rota*, Blanford; Cret. Ceph. Ind., 38, pls. 24 and 25.

Two specimens of this species were found, one of which, after breaking away the outer whorl, furnished a specimen two inches in greater diameter. The edges of the septa are distinct and show the characteristic curves. It has also the closed umbilicus and narrower ventral margin and outline of *N. rota*, but is rather narrower and has not the surface markings. The larger specimen resembles *N. texanus* (?), (Shum), Gabb. It is possible that this species of Gabb will eventually prove to be identical with *N. rota*, Blanford.

Gyrodes pansus, Stol.; Cret. Gastr. Ind., 305, pl. 22.

Six specimens of this fossil were found all in fair preservation and two of which were exceptionally good. The characteristic markings, low spire and outline all indicate that there can be no doubt of its proper identification.

Avicula nitida, Forbes; Trans. Geol. Soc. Lond., VII., 151; Peleo. Ind., 404, pl. 24.

Six specimens were collected of this shell which show clearly all the characteristic features of the species. The fossils are all well preserved.

Inoceramus labiatus, Schloch; Bronn's Jahrb., VII., 93; Proc. Acad. Sci. Phil., 1857, 119; Can. Mes. Foss., I., part 3, 193; U. S. Geol. Sur. Bull., 106, 77, pl. 14.

Ten quite perfect half-shells, besides a large number of fragments of this species were obtained. The shells agree so well with Meek's description that there can be no room for any other reference.

Pectunculus sagittata (?), Gabb; Cal. Pal., I., 197, pl. 131; U. S. Geol. Sur. Bull., No. 51, 39.

A number of specimens of this shell were found in very good preservation, which resemble very closely *P. subplantata*, Stol., but being uncertain as to their identity with this species, I have preferred to refer them to *P. sagittata*, Gabb, in view of what has been said by Professor White as to the absence of the sagittate markings.

F. M. ANDERSON.

STANFORD UNIVERSITY,
California, May 8, 1895.

GLACIAL STUDIES IN GREENLAND. V.

The Redcliff Peninsula.

From the north side of the deep inlet formed jointly by Murchison Sound and Inglefield Gulf, McCormick Bay sets back to the northeast, while Bowdoin Bay, which lies to the east of it, sets back to the northwest. The result of these convergent courses is to bring the heads of the two bays near each other and to enclose a sub-triangular area whose three sides may b e roughly taken as fifteen miles in length. Between the heads of the bays the ground is low and partially occupied by lakes which gives further emphasis to the peninsular character, for the most of the area is a plateau and this low tract has the moral effect of a partial disseverance. The margin of this plateau to a width varying from a few rods to perhaps three miles is bare of ice, except as glacial tongues intrude upon it. This portion reaches about 2000 feet in height. The central portion of the plateau is covered by an ice-cap, which, according to Lieutenant Peary, mounts up to 4000 or more feet in altitude. Whether this means that the ice is 2000 feet thick or that the land beneath the ice swells upward is a matter of uncertain interpretation. The configuration of the summit favors the view that the land participates in the increased elevation to some notable degree, but the ice is obviously thick. From this ice-cap tongues creep down into the valleys on all sides of the peninsula. They even descend to the northward upon the low neck connecting the peninsula with the mainland. Two of these ice-tongues on the south, two on the east, and one on the north were examined at hand. The others were only cursorily seen at greater or less distances.

Local ice-caps while almost immeasurably inferior to the inland *mer de glace* in general interest and significance are nevertheless in certain respects not only equal but even superior to it as factors in glacial study. They define more sharply the limitations

of glacial accumulation. The occurrence of the border of the inland ice sheet at given elevations leaves us in doubt whether its presence signifies that the conditions of glaciation are there present normally, or whether the ice has simply been pushed forward to that point by the *mer de glace* back of it. Local ice-caps, on the other hand, show that the conditions of glaciation are unquestionably present. They thus enable us to determine quite accurately what elevations (under existing conditions) are adequate to produce glaciation, and to fix the limit of adequacy. So also, equal elevations being chosen as a basis of comparison, the local ice-caps furnish the means of estimating the relative influence of meteoric conditions.

The ice-cap of Redcliff peninsula is an excellent example of the plateau variety of the local type. It suffers no interruption from mountain peaks. It spreads in an unbroken sheet over the whole interior and creeps outwards in all direction. In this last feature it is felicitous in permitting, within so narrow limits, the study of glacial tongues moving toward all points of the compass.

The Fan glacier.—The most westerly of the tongues from the ice-cap of Redcliff peninsula has been designated the Fan glacier from the beautiful deployment of its lower portion.[1] It is but a lobe of the peninsular ice-cap descending a broad valley excavated in the shales and sandstones that constitute the uppermost division of the clastic series, which has been previously described. While no measurements were made, it will probably not be very far from the truth to regard its length as three miles and its breadth as falling little short of one mile. The glacier declines with a gentle and regular slope that imparts great beauty to its longitudinal profile (Fig. 23). This doubtless indicates much smoothness in the floor over which it is advancing, as well as freedom from lateral constrictions and topographic strains of all kinds. Its transverse profile, as seen from the valley in front is singularly symmetrical and graceful (Fig. 24). It is doubtful

[1] A figure of this glacier is given by Professor Angelo Heilprin in Popular Science Monthly, November 1894, p. 12.

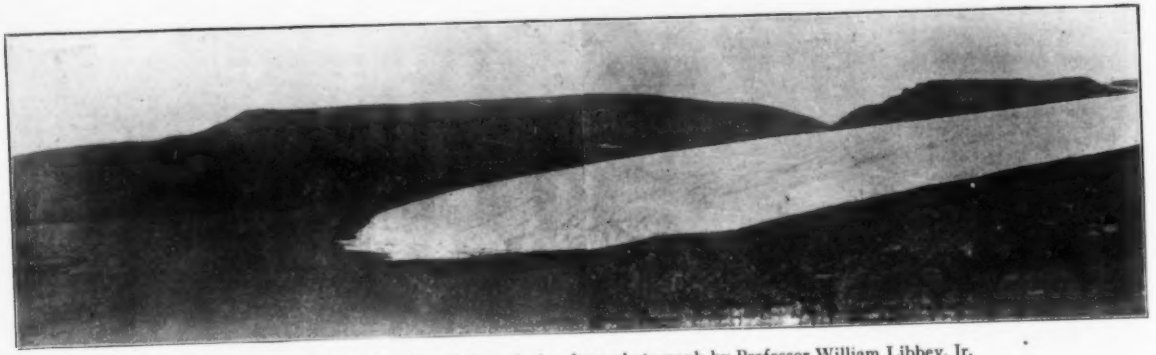


FIG. 23. Longitudinal profile of Fan glacier, from photograph by Professor William Libbey, Jr.

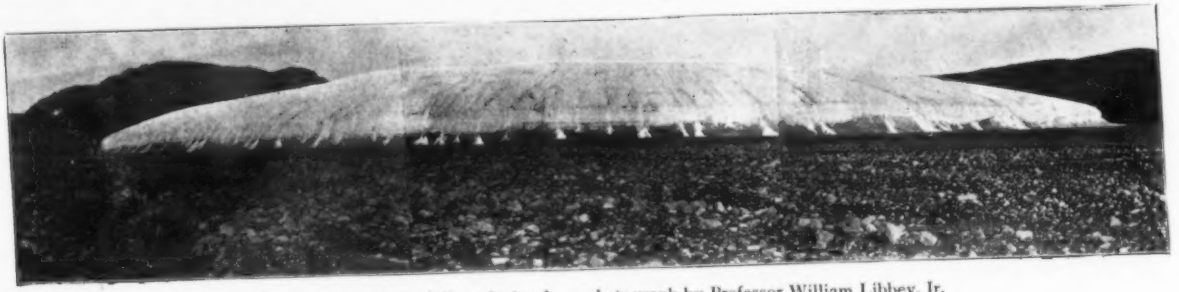


FIG. 24. Front view of Fan glacier, from photograph by Professor William Libbey, Jr.

whether any known glacier exceeds it in the beauty of its superficial curvatures. The foreground in the illustration shows that it is resting upon a plain formed by the deposits of its own waters, and to this its symmetry is doubtless chiefly due. It may be taken as a rare type of the behavior of ice in an exceptionally untrammeled situation under the conditions of a high northern latitude. The photographic illustrations express for themselves the angle of the slope and the law of the profile's curvature.

Next to its graceful contours the steep front invites attention. It will be observed in the figures (Figs. 23, 24, 25, 26 and 27) that at the base there is an embankment, presently to be described, above which the ice rises nearly vertically to a height about seventy-five feet above the plain. Above this there is an arching but receding brow, the curvature of which becomes more and more gentle as it retires from the face. It will be seen that the verticality of the face maintains itself throughout all its arching course across the valley, and that it is as pronounced in the center as at the sides. The verticality is obviously due neither to lateral nor to central agencies as such. It cannot be attributed merely to the reflection of rays from surrounding elevations, for there are none opposite its wide frontage. The gravel plain spreads uninterruptedly down to the gulf. It will not be wise to draw conclusions respecting the cause of this verticality of face at this point, as we shall have occasion to note the phenomenon in much more pronounced forms in a dozen or more glaciers which present various attitudes and diverse environments.

Along the base of the glacial front it will be observed that there are numerous white cones (Figs. 24, 26 and 27), and between these a sloping embankment resting against the steep face of the glacier. Rising from each of the white cones there may be seen lines which reach back across the brow of the glacier and are lost upon its upper surface. These are little channel-ways cut by streamlets formed on the surface of the glacier by its melting. As these streamlets coursed rapidly down their little channels they dislodged coarse granules of the ice, loosened by the sun, and carried them away and, precipitating them over the face

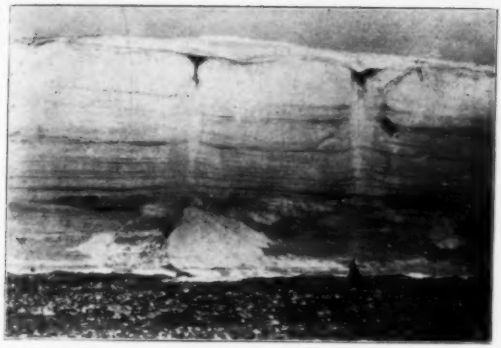


FIG. 25, Face of Fan glacier. Photo. by Prof. Wm. Libbey, Jr.

FIG. 26. Cones in front of Fan glacier. Photo. by Prof. Wm. Libbey, Jr.

FIG. 27. Terminal profile and cones of Fan glacier. Photo. by Prof. Libbey, Jr.

of the glacier, heaped them up in cones at its base. Not only was this indicated by the structure of the cones themselves, but the process of their formation was observed in actual progress.[1] Its rapidity was something surprising. As the granules were brought down the ice-wall by the cascading rivulet they occasionally struck projections and bounded forth into the air and fell upon the slopes of the cone. In other cases they were seen to leap forth from the rivulet when it struck the summit of the cone; but in the main they simply gathered at the apex of the cone until they blocked up the little channel-way and forced the rivulet to seek another course only to be blocked in turn and thus forced to and fro, building up the cone symmetrically. The rapidity of action observed was doubtless somewhat exceptional for the day was unusually bright and warm. It is doubtful whether it was equaled by more than ten days during the entire season.

The embankment between the cones had a well developed granular structure, but it appeared to be formed in considerable part from wind-drift accumulations. It was very notably solidified into a half-ice. The surface was covered with dirt and to some extent with rocky and earthy débris that had fallen from the face of the glacier. From its solidity, dirtiness and other features it seemed scarcely possible that it was the product of the current season solely. As may be inferred from the illustrations, it lay close against the front of the ice-wall rising in some places half its height. Nowhere did I observe any disruption or crumpling of the embankment as though the glacier had crowded against it since it was formed, nor, on the other hand, it is scarcely needful to say, was there any crevasse or interval between it and the glacier, indicating a retreat of the ice. Such retreat would only be produced by the melting of the glacier backward faster than it moved on, and such melting could scarcely be supposed to take place without involving the destruction of the embankment as a concurrent, if not a prerequisite, condition. Manifestly melting could not have counteracted the onward movement at the base of

[1] PROFESSOR LIBBEY was the first to note the action in progress.

the glacier because of the protection interposed by the embankment itself. It is obvious that this phenomenon suggests, if it does not demonstrate, the inertness of the glacier at its extremity. It is difficult to see how it could be moving at any appreciable rate at its end without some disruption of the embankment, unless it be supposed that the embankment was pushed bodily forward as though a part of the glacier itself. In this case there would be reason to expect disruptive phenomena at the forward edge of the embankment, none of which was observed.

The existence of the numerous streamlets on the surface of the glacier and their size, indicating that they had run considerable courses, is an index of the freedom of the lower part of the glacier from crevasses. This freedom is in signal harmony with the smoothness of its bottom and the slowness of its motion. It is interesting in this connection to note especially that it is not longitudinally crevassed, as is the Rhone glacier, which fans out at its foot in a somewhat analogous, but far less beautiful fashion.

Though not the most obtrusive, perhaps the most important feature displayed by the glacier was its stratification. Standing before its face at any point, it might be seen to be formed of definite layers and even of laminations. The photographic illustrations exhibit this in some measure, but the variation in light between the alternations of the more solid and the more porous ice was too delicate to be fully caught by the camera. The simplest form of the stratification consisted of alternations of porous, opaque white layers with solid translucent blue ones. The blue sheets were thin, while the white ones were relatively thick. The more conspicuous variety of stratification was formed by the introduction of rock rubbish between layers of relatively pure ice (Fig. 25). In the Fan glacier, this reached a far less notable development than in the glaciers which will hereafter claim our attention. But even there it was sufficiently pronounced to be a very notable feature. It is important to observe that the rocky material was distributed in definite horizons between the ice layers. It was not promiscuously scattered through the ice. The débris varied in coarseness from bowlders of large

dimensions downward to fine silt. The coarse and fine material were not separated. It was not a phenomenon of assortment Coarse and fine were arranged along the same horizons. The layers or laminæ of ice which were close together where only silt and sand were present separated so far as needful to admit bowlders. It was interesting to observe that the laminæ as they approached a bowlder parted, a portion curving over the bowlder and a portion curving under it. No good photographic illustrations of this were secured from this glacier, but fair ones from other glaciers will be given later. Many of these other glaciers show the phenomena of stratification and the inclusion of débris so much more clearly and pronouncedly that we may leave further details to be subsequently described.

The débris was enclosed almost exclusively in the basal beds, the upper portion of the glacier being almost entirely free from rocky material. The distribution throughout the lower layers was not strictly progressive from the base upwards. Higher layers sometimes contained more than lower ones, but the general fact of basal distribution was very pronounced. It was further observed that there was more débris in the layers near the sides of the glaciers than in the central portion. This is expressive of a law which somewhat widely obtains.

The top of the glacier was not reached by us, but from what could be seen it appeared to be essentially free from bowldery erratics, though somewhat discolored by atmospheric dust.

The débris which was embedded in the Fan glacier was largely composed of a hard pinkish sandstone derived from the middle member of the clastic series previously described. There was present, however, a considerable sprinkling of crystalline bowlders of the granitic type and occasionally bowlders of the greenstone type. If it is recalled that the source of this ice-flow was probably not more distant than the middle of the peninsula, the stratigraphy beneath the glacier is readily inferred. The uppermost member of the clastic series which occurs in the sides of the valley adjacent to the lower part of the glacier must soon be replaced at the surface by the rising of the pink sandstone

from beneath it. This in turn must soon be replaced by the crystalline terrane, which apparently constitutes the nucleus of the peninsula; indeed the crystalline terrane was afterwards observed to come out to the edge of the peninsula on its east side facing Bowdoin Bay. The material in the base of the glacier must apparently have been picked up from the rocky surface beneath the ice-cap. The derivation was apparently basal. Some part of it, however, may have been introduced laterally as it descended from the plateau into the valley. This seems to be indicated by the fact that the sides of the glacier contained somewhat more débris then the central portion.

The material in the ice was somewhat rubbed and scratched but not markedly so. Indeed the first impression was that of unsubdued angularity, but observation showed that some abrasion had been suffered by a considerable percentage of the blocks included. Well rounded and thoroughly striated bowlders were rare, though present. This, however, was scarcely typical. Similar material in other glaciers observed was notably bruised and scratched. Very likely the angularity in this instance is an effect of the open, free course which this glacier enjoyed in its relatively broad, straight valley.

At the edge of the ice, the embedded débris was being freed by melting and was dropping in front. The amount of débris in the ice being scant, the accumulation was small. There was an almost complete absence of any terminal moraine in front of the glacier. This will be seen by consulting the photographic illustrations. If any terminal ridge had been formed, it was either concealed beneath the margin of the glacier or by the frontal embankment above described. The latter could not have afforded a general concealment because its continuity was not complete. At some points the smooth gravel plain of the valley below could be traced up to the actual front of the ice. Nor was there any notable moraine along the sides of the glacier. As in the case of the Igloodahomyne glacier the drainage was chiefly accomplished by a stream on each side occupying a trench between it and the valley sides. Sometimes the lateral

stream tunneled under a portion of the ice, leaving a bridge arching over it from the body of the glacier to the side of the valley. In other cases the stream cut across the edge of the glacier dissevering a portion of it. These were cases in which the wash from the slope of the adjacent highlands was very considerable and encroached upon the glacier, burying the part that became dissevered. It was interesting to observe that much of this buried ice was exceptionally pure and solid. In other portions, however, it contained interstratified débris, and at some points there were irregular impregnations of rocky material.

On the east side there was a very significant phenomenon displayed in connection with an embossment or buried spur of rock (Fig. 28). The lateral stream of the glacier crossed the neck of rock connecting this with the valley side, cascading over it and cutting a channel in it. Next to the glacier the rock rose somewhat and was covered at the foot of the ice-wall which formed the side of the glacier by a talus derived from the lower layers of the ice. If reference is made to Figs. 28, 29, and 30 much unsatisfactory description may be avoided. It will be observed that near the base of the glacier there is a dark belt which consists largely of stony débris held in the matrix of ice. Below this, not well shown in the figure, there is ice less freely charged with rocky matter. Above this it will be seen that there are at intervals several dark lines, which are simply rock rubbish sandwiched between layers of ice. The notable feature is the curve which these assume. At the right, or up-stream end, the layers rise by beautiful curves which gradually flatten as they pass over the embossment. Beyond the summit they descend, gently at first, but more rapidly later. When they have reached a point some distance below the embossment, they bend backwards to varying extents and with various degrees of abruptness. The curvature is least abrupt near the embossment and increases generally with distance. The recurved portion nearest the embossment is short and its lower end soon becomes obscured by the fallen débris. The higher layers return farther

FIG. 29. Curving of laminæ, east side of Fan glacier. Photograph by Prof. Libbey.

FIG. 28. General view of laminæ curving over embossment of rock and drift. Photograph by Prof. Libbey.

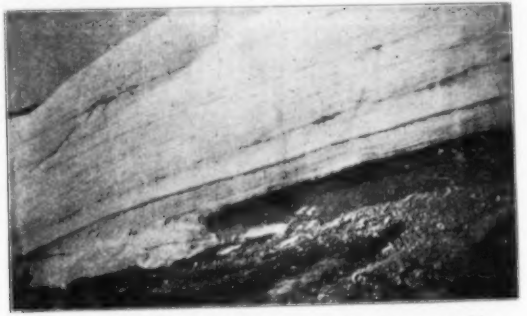


FIG. 30. Recurving laminæ below embossment, east side Fan glacier.

and the one several feet above the broad dark band after curving sharply about runs several rods backwards before it is lost from sight under the sloping débris. (See Figs. 29 and 30.)

The drumloidal[1] nature of the curve described by these layers is very suggestive, and it is perhaps not too much to believe that the essential principles of drumlin formation are here expressed. It will be wise, perhaps, to defer inferences and special discussions until other phenomena of like nature are described and a broader basis for induction is laid.

T. C. CHAMBERLIN.

[1] I suppose that drumlinoidal is the rigidly correct adjective to use here, but as drumloidal is briefer and better in itself, it seems preferable to be governed by the euphonies and utilities of language than by the stiff formulas of a conventional grammar.

STUDIES FOR STUDENTS.

GEOLOGIC STUDY OF MIGRATION OF MARINE INVERTEBRATES.

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INTRODUCTION.

THE migration of invertebrates is necessarily too slow to be observed in a few years, and only many successive generations of observers could throw light on it. While the present habits of these animals may be studied and inferences drawn as to their history, these inferences are probably often incorrect. The common inference that fossil corals indicate a warm sea is an example; by this method the existence of a tropical sea in the Arctic regions during Palæozoic time has been inferred, and therefore great changes in physical geography. But it is well known that the elephant and the rhinoceros, which we regard as typical tropical animals, lived in the Arctic regions of the northern

hemisphere during the Glacial period. Also the Bryozoan group Cyclostomata are, as fossils, widely distributed in temperate regions, but the living forms of these are decidedly Arctic.

The present distribution of animals shows many anomalies, many groups being present where naturally, according to their habits elsewhere, they ought to be lacking, and being absent where, according to analogy, they ought to be present.

It is clear then that a study of the present distribution and habits of marine animals can throw little light on their history. But the geologist does not confine his observations to the present; geologic history is a book whose leaves are scattered in many parts of the earth, and each observer gathers some of these leaves.

A study of the distribution of animals in past time ought to explain their present occurrence, and the laws governing their distribution; and incidentally light should be thrown on the extinction of faunas, and upon changes in physical geography that accompanied and caused the migrations and extinctions.

ZOÖLOGICAL PROVINCES.

Modern Provinces.—One of the first facts in the study of geographic zoölogy that attracted the attention of naturalists was that animals are not distributed strictly according to climate, or other physical conditions. This was inexplicable, according to the views then held. The work of Edward Forbes upon the *Natural History of the European Seas* began the scientific study of the distribution of marine animals. Forbes formulated the theory of generic and specific centers. Each genus and each species was to him a reality, and by distribution of these from the centers he satisfactorily accounted for their occurrence in other places. Although reasoning upon the theory of special creation for each species, Forbes recognized the fact that species and genera are never intermittent except locally. His results therefore do not differ in any respect from those obtained on the basis of development of one species out of another. He showed too that while separated regions under the same conditions show great similarity of faunas, this similarity is due rather to representative than to

identical species or genera. What better argument could be adduced for the influence of surroundings on development?

S. P. Woodward[1] while working upon the same theory as Forbes reaches the following conclusion: "Meanwhile it may be stated that according to this evidence [that derived by Forbes from Palæontology] the faunas of the provinces are of various ages, and that their origin is connected with former (often very remote) geological changes, and a different distribution of land and water over the surface of the globe." It must be remembered that this was written several years before the publication of Darwin's *Origin of Species*, at a time when the teachings of Lamarck had been practically forgotten, and by an author that believed in the reality of species.

The marine provinces that were proposed by Woodward[2] for the invertebrates hold good even now. They are as follows: (1) Arctic, (2) Boreal, (3) Celtic, (4) Lusitanian, (5) Aralo-Caspian, (6) W. African, (7) S. African, (8) Indo-Pacific, (9) Australo-Zealandic, (10) Japonic, (11) Aleutian, (12) Californian, (13) Panamic, (14) Peruvian, (15) Magellanic, (16) Patagonian, (17) Caribbean.

And these provinces[3] are grouped naturally into great regions:

"The tropical and sub-tropical provinces might naturally be grouped in three principal vivisions, viz., the Atlantic, the Indo-Pacific, and the West-American,—divisions which are bounded by meridians of longitude, not by parallels of latitude. The Arctic province is comparatively small and exceptional; and the three most southern faunas of America, Africa, and Australia differ extremely, but not on account of climate." An application of this same method enabled Wallace to write his *Geographical Distribution of Animals* and to place the study of the geographic distribution of all animals on a scientific basis.

[1] Manual of the Mollusca, 1856, p. 352.

[2] Manual of the Mollusca, 1856.

[3] Loc. cit., p. 353.

ANCIENT PROVINCES.

There were no such things as universal faunas, even in remote geologic time; there have always been barriers of continent and ocean, and probably too of climate, ever since life existed on the earth. Only the deep sea faunas could be universal, if oceanic bottoms had been stable, but even they are not universal now, nor have they remained unchanged in time.

Barrande showed that the known Cambrian and Silurian faunas could be divided into well-defined provinces, and the recent work of Professor Walcott has extended greatly our knowledge of the distribution of Cambrian animals.

For the geographic study of Devonian faunas we are especially indebted to Barrende,[1] and H. S. Williams.[2]

It has been shown conclusively by the latter author that in Lower and Middle Devonian there was a North-South American region, and a Eurasian region; and that during Upper Devonian times the regions had changed so that the grouping was into the Eurasian-North American, and the South American-South African.

We owe most of our knowledge of the faunal geography of the Carboniferous to Professor Waagen.[3] He has shown that during the Carboniferous there were two great regions corresponding to the northern and the southern hemispheres, and that within these were provinces more or less sharply defined. But these regions and provinces by no means agreed with those of the older Palæozoic.

Mojsisovics[4] has divided the known Triassic faunas into two great regions, the European and the Pacific, and these in turn into provinces; the European Mediterranean province, the Arctic; the Himalayan, which is intermediate between Arctic and Mediterranean; and the American.

[1] Système Silur. Bohème.

[2] Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer., Vol. I.

[3] Pal. Indica. Salt Range Fossils. Geological Results.

[4] Arktische Triasfaunen, Mém. Acad. Sci. St. Petersbourg, VII. Series, Vol. XXXIII., No. 6.

But during the Lower Trias the Arctic, the Himalayan, and the American provinces had closely allied faunas, and might be grouped together in contrast to the Mediterranean. In the Middle Trias, however, the American Triassic province was being gradually cut off from the Arctic, and communication established with the Mediterranean. This connection through the Himalayan province was very complete in the Upper Trias, and all three might be grouped under one region, the Mediterranean-Indian-American.

Neumayr[1] has worked out the provinces of Jurassic time, and grouped them in two regions, the Boreal, and the Central-Mediterranean. He has also traced out for that time the distribution of climatic zones by means of the Boreal type, the North Temperate type, the Alpine or Equatorial, and the South Temperate.

To the Boreal region belong the Russian, the Siberian, the Himalayan, and the Alaskan provinces. To the Central Mediterranean region belong the Northern European, the Alpine, the Salt Range, the Southern Indian, the Australasian, South American, and the Western American. But during Upper Jura the Western American province took on an Arctic character, and certainly became part of the Boreal region. Thus these regions and provinces will not hold good for any long-time division, but were always, though slowly, changing.

The study of the distribution of fossil faunas as influenced by climate was begun by Ferdinand Roemer,[2] who recognized that the Cretaceous of England, northern France and Germany has a fauna similar to that of New Jersey, and that the faunas of southern Europe, north Africa, and Texas are similar. These differences Roemer ascribed to climate, noting that at that time, as today, in America the isothermal lines came much further south than in Europe. Neumayr[3] has carried these studies forward, correlating the various observations made since Roemer's time.

[1] "Geogr. Verbreitung der Juraformation," and "Klimatische Zonen wärend Jura und Kreidezeit."

[2] Kreidebildungen von Texas, Bonn, 1852.

[3] Klimatische Zonen wärend Jura und Kreidezeit.

It is now known that the Cretaceous of South America belongs to the tropical type, as does also that of Mexico.

Still more recent observations have shown that the Cretaceous of western North America belonged during the Neocomian or Knoxville to the Boreal or Russian type, but this resemblance soon died out, and that the Horsetown or Gault fauna was of central European type, like that of India. This kinship to the Indian faunas persisted until the end of the Cretaceous. Since Cretaceous time the marine provinces seem to coincide closely with the existing boundaries of the temperature and shore lines.

MIGRATION.

Causes of migration.—The lower forms of life produce many more young than can possibly come to maturity; hence a lively competition ensues between those of like character as well as between those that are different. Under these conditions an equilibrium is attained, the field supports the maximum population, and all others migrate or perish.

Thus migration would be a necessity even if the conditions remained always the same and the competition were always between members of the same fauna. But conditions never remain the same. The same causes drive individuals from one habitat and to another, and disturb the equilibrium there established. A disturbance taking place in an unimportant part of a province must therefore disturb the whole zoölogical region. And if we add to this changes in physical geography, we see that constant migration and intermigration must be a necessity. Any rising or sinking of shore lines would drive the inhabitants from their dwelling places; each change in the outline of continents changes the direction of currents, and thus has a marked influence on migration.

Extinction of faunas.—Today it is noticed that when the struggle for existence becomes too severe for a species it disappears. But the reason for this disappearance has always been uncertain. In geologic history a species has a certain length of life and dies out, never to reappear. The supposed contemporaneous extinc-

tion of a species all over the earth has led to the theory that species, like individuals, have a limited life, and that in time they reach a stage of development where they can go no further, and then of necessity die out.

This idea would be all very well if species dropped out one at a time, but in reality they usually go and come by faunas. It would seem, then, that changes in physical geography have had more to do with the extinction of faunas then anything else. This becomes the more probable when we reflect that species are not extinguished contemporaneously over the earth, but rather that their appearance and extinction have been used by geologists in a misleading way to prove synchronism of strata.

Remarkable cases of survival of types have long been known, as of *Trigonia* in the Australian waters, and of *Pholadomya* in the Antilles. Survivals of faunas are constantly coming to light. Dr. W. H. Dall[1] has shown that a large proportion of the Pliocene and even Miocene invertebrates of the Southern Atlantic Gulf states are still found living in the archibenthal region off the present coast. The same thing is true of the California coast, but here we have an even more remarkable example. Dr. A. C. Lawson,[2] from purely geologic evidence, has reached the conclusion that Santa Catalina Island has remained above water during Quaternary time, while most of the neighboring country was submerged. This stability of conditions has shown itself in a unique survival of the marine fauna, for Dr. Cooper's[3] list of the fossil mollusca of the California coast shows five species still living on Catalina that are known elsewhere only as fossils, and many species that are now known living in other remote zoölogical provinces. Similar cases of survival occur in ancient geologic formations.

Dr. C. R. Keys[4] called attention to a reappearance of a Waverly fauna in the Burlington of Missouri. A similar occur-

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 186.

[2] Univ. Calif. Bull. Dept. Geol., Vol. I., No. 4, p. 135.

[3] Calif. State Mining Bureau, Seventh An. Rep. 1887.

[4] Am. Jour. Sci., Dec. 1892, p. 447.

rence was described by the writer[1] and by Professor H. S. Williams[2] in the Fayetteville Shale, Lower Carboniferous, of Arkansas. A survival of a Devonian fauna in rocks of Lower Carboniferous age has been described from Nevada by Professor C. D. Walcott,[3] and from California by the writer.[4]

It is becoming more evident all the time that the range of faunas, instead of being usually the same in widely separated regions, is usually different, and that strata can no longer be called synchronous from the occurrence in them of similar faunas.

In reality they can no longer be called homotaxial with any degree of certainty, unless we know in what direction the faunas migrated, since homotaxis in the palæontologic sense does not agree with homotaxis in the stratigraphic sense.

The extensive extinction of life at one place earlier than in another has also been noted. Professor W. Waagen[5] has suggested that the glaciation in the southern hemisphere toward the end of the Carboniferous killed off the Palæozoic flora earlier than was the case in regions where there was no glaciation. Such phenomena approach the nature of "catastrophes," and show that Cuvier's doctrine was not so far wrong after all.

The study of the distribution of faunas in the past seems to show that their extinction has been chiefly due to changes in physical geography; and that where conditions remained constant the faunas remained unchanged. This study too suggests that no part of the earth has remained unchanged, for while some of the abysmal regions may be very old, even their faunas are of comparatively modern aspect.

MEANS OF MIGRATION.[6]

Few invertebrates are rapid swimmers. Many are attached forms and the majority are only crawlers. But all are free at

[1] JOUR. GEOL., Vol. II., p. 198.

[2] Am. Jour. Sci., III. Ser. Vol. 49, pp. 94–101.

[3] Monograph VIII. U. S. Geol. Survey.

[4] JOUR. GEOL., Vol. II., p. 595.

[5] Pal. Indica. Salt Range Fossils. Geol. Results, p. 240.

[6] Accidental distribution need not be considered here; it may have occurred, but must have been very rare.

some time in the life of the individual or cycle. This is often in the larval state, but it is known that certain species of brachiopods, which are swimmers only in the *cephalula* stage, are distributed over thousands of miles. It is an important fact that ammonites, which were free in the adult stage, and may have been swimmers, though most probably chiefly crawlers, are not distributed much more widely than lamellibranchs or others of the lower invertebrates. Thus the Upper Triassic fauna of California contains many species that are found in the Alps and the Himalayas, and among these there are several species of the *Aviculidæ*, which in the adult stage were attached by a byssus. The Lower Cretaceous Knoxville fauna of California contains along with ammonites a good representation of European lamellibranchs; and the Horsetown and Chico faunas of California contain fully as many species of lower invertebrates as of ammonites that may with probability be referred to foreign species. It is clear, then, that their distribution has been due to faunal, rather than to individual migration. Faunal migration can only be possible under physical agencies acting slowly, and on a large scale. Marine currents along shore lines have been efficient aids to migration, not so much by transporting the young, as by transporting conditions suitable for life.

Even with our currents continental margins offer ample opportunities for faunal migration, for the crawling adults or the swimming young can find the constant conditions of depth, temperature and food supply suitable for their life.

Dr. W. H. Dall[1] has recently shown that tides on the archibenthal continental margins have been influential in distributing faunas. But probably the great agent of distribution has been the slow shifting of shore lines, which not only aids but also compels migration.

BARRIERS TO MIGRATION.

Land barriers.—Land masses present an insuperable barrier to all marine invertebrates; but if the bodies of land are short, and

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 179.

do not reach into polar waters, animals can easily pass around the ends. Thus the molluscan fauna of the Mediterranean does not differ appreciably from that of the English waters, because in the passage around the peninsula of Spain animals remain in temperate waters, and under nearly the same conditions.

On the other hand, the Isthmus of Panama separates two faunas absolutely distinct from each other; the same thing is true of the Isthmus of Suez.

East and west land masses would therefore not be very effectual barriers since they would not be so likely to extend into polar waters or into great differences of temperature.

Climatic zones.—That climatic zones are today partial barriers to migrants along the coast is shown by the difference in faunas living in northern and in southern latitudes under the same conditions. From the very nature of the case we should expect that cold water species would be able to cross climatic zones more easily than those adapted to warm water, since, as Dr. W. H. Dall[1] has shown, a fall of a very few degrees below the temperature favorable to life is more destructive than a rise of many degrees.

In the present we have no means of testing this, but facts brought to light by geology confirm it. The Jura of Central Europe and of the Argentine Republic in South America have the same fauna, which, in reaching one of these regions from the other, must have passed from temperate waters through tropical, and into temperate seas again. Also the faunas of the uppermost Jura and the lowest Cretaceous of Russia, which must have been Arctic in character, have migrated southward along the West Coast, almost into tropical waters. On the other hand we know of no case where equatorial faunas have passed through Arctic regions and even passages from tropical into temperate regions must be exceedingly difficult.

The genera *Lytoceras* and *Phylloceras* are common in the Neocomian, Lower Cretaceous beds of southern Europe; but although these waters were undoubtedly in direct connection

[1] Bull. Mus. Comp. Zoöl., Vol. XII., No. 6, p. 180.

with those of northern Europe, *Lytoceras* and *Phylloceras* are lacking in the latter region. Also in the lower part of the California Knoxville beds the above mentioned genera are unknown, and come in only higher up where the first members of the tropical Indian fauna began to come in.

Water barriers.—By far the greater part of marine animals live near the shore, and are unable to exist under other conditions. To these an abysmal sea is as impassible a barrier as a continent. But an east-west sea affords good opportunity for passage from one side to the other simply by slow progress along the margin. The fauna of the Mediterranean is a good evidence of this, the animals on the European shores not differing appreciably from those on the African.

And even on the opposite sides of great north and south oceans there are usually many species in common; the Atlantic shore American fauna has many European species, and the Pacific shore harbors many from Asiatic waters. Their passage was effected in most cases along continental borders that have since been obliterated by subsidence and erosion. We have an abundance of independent geologic evidence that such recent changes have taken place, for example the destruction of the Antillean continent since Tertiary time, as worked out by Dr. J. W. Spencer.[1]

No doubt just such great recent changes in the distribution of land and water could be worked out in the Indian ocean, by application of the same method of study. The studies of Neumayr,[2] Waagen[3] and Suess[4] have demonstrated the existence of a continent in that region during late Palæozoic and early Mesozoic times, connecting Australia with Asia.

By a study of the geographic distribution of animals Wallace[5] has shown that in comparatively recent times Australia was

[1] Bull. Geol. Soc. Am., Vol. VI., 103–140.

[2] Geographische Verbreitung der Jura formation.

[3] Palæontologia Indica.

[4] Antlitz der Erde.

[5] Geograph. Distrib. Animals, Vol. II., The Australian region, pp. 387–485.

connected with many of the now scattered islands of the Indian Archipelago, but was separated from Asia.

Deep seas afford no barriers to rapid swimmers or to any pelagic forms, or to dwellers in the deeps. These approach much more nearly universal distribution, the first two being checked only by continental barriers, and the latter only by shallow waters.

CRITERIA OF MIGRATIONS.

Occurrence of identical or very closely related species and faunas in widely separated localities is good evidence of migration from one of these localities to the other, or from another region to both of them. In most cases, however, what are called identical species are in reality only representative forms.

As long as ideas about stratigraphic units were loose, and species had too broad a significance, it was impossible to recognize slight changes in faunas and age. Oppel[1] from his study of the Jura gave to geology the idea of stratigraphic zones, each with its characteristic animals. He recognized the importance of selecting types of great horizontal and narrow vertical distribution, and for this reason, where it was possible, chose ammonites as zone fossils.

This work would never have been possible had not Barrande[2] introduced an extremely narrow idea of species. Neumayr carried this study further by introducing the idea of "mutations" for genetic series of forms occurring in succeeding zones.

The use of these principles enables the naturalist to draw sharp lines between successive faunas.

Sporadic occurrence.—It is often noticed that species or faunas are intermittent in their occurrence, and this too when it is not due to difference of facies. Just such a case is the reappearance of the Waverly fauna in higher beds of the Lower Carboniferous of Missouri and Arkansas, already alluded to in this paper. The intercalations of marine beds in the fresh-water deposits of the Coal Measures is another good example.

[1] Juraformation.

[2] Système Silur. Centre Bohème.

In the Jura of northern Europe, according to Neumayr,[1] the genera *Lytoceras* and *Phylloceras* appear only sporadically, being lacking entirely in sixteen zones; and the known species in that region do not belong to a genetic series. But in southern Europe these genera appear plentifully in all the zones, and do represent genetic series.

The migration northward at several successive periods is thus clearly established. In these same beds the genus *Amaltheus* also appears intermittently; but no region is yet known where *Amaltheus* developed continuously. Among the Jurassic ammonites of northern Europe there are a number of cryptogenic types, most of which coincide with the *Amaltheidæ* in their appearance and therefore came from the same region.

These facts go to show that the principles on which Barrande's[2] doctrine of colonies was founded were not far wrong, although it has since been found that his colonies were only younger rocks carried into the midst of older beds by dislocations.[3] Barrande's idea was that younger faunas are sometimes intercalated with older ones by changes in physical geography. The modern doctrine of colonies on the other hand is that older faunas have often been preserved by survival in places where no great changes have taken place, and that these older faunas have been intercalated with the younger by changes in physical geography.

Heterochronous appearance.—By heterochronous appearance of forms is meant their occurrence at different horizons in separated regions. Now it is well known that a species seldom occurs at exactly the same time in two widely separated places; it must originate at the one and migrate towards the other. This migration takes time, and the species may be entirely extinct at the point of origin before it reaches the second place. But geologists have commonly used species as criteria of horizons, when in

[1] Jahrb. K. K. Geol. Reichsanstalt Wien. Bd. 28, 1878. Ueber unvermittelt auftretende Cephalopodentypen im Jura Mittel-Europas.

[2] Système Silur. Centre Bohème, Vol. I., p. 73, etc.

[3] J. E. Marr, Quart. Jour. Geol. Soc., 1880, p. 605, 1882, p. 313.

reality this should be subject to much greater limitations than even the ideas of homotaxis, as formulated by Huxley,[1] would demand.

Faunas need not and do not appear at the same horizon, nor even in the same order of succession, all over the world, for an intermigration between two distant localities would produce an apparent inversion of the two faunas at either place.

The genus *Clymenia*, according to Professor J. M. Clarke,[2] appears in the *Goniatites intumescens* beds of New York ; in Europe *Clymenia* is wholly unknown in the *Intumescens* fauna, but is the characteristic form of the next higher division of the Devonian, where the *Intumescens* fauna is already extinct.

In the Upper Trias, Karnic stage, of California, *Rhabdoceras* and *Halorites* occur, although *Rhabdoceras* is known in the Alps only from the higher Jura stage, and *Halorites* in both Alps and Himalayas is characteristic of the latter horizon. Also in the Hosselkus limestone, Upper Trias, of Shasta county, California, *Trachyceras* and *Protrachyceras* occur, in the zone of *Tropites subbullatus*, and associated in the same rocks with a characteristic *Subbullatus* fauna ; but in the Alps and in the Himalayas *Trachyceras* and *Protrachyceras* are older than the *Subbullatus* fauna, and never occur in the same beds with it. The question then remains, Did *Trachyceras* and *Protrachyceras* survive longer in America than in Asia and Europe, or did the *Subbullatus* fauna reach here earlier? The researches of Mojsisovics[3] show that *Tropites* is probably indigenous to the Arctic-Pacific Triassic province, and that *Trachyceras* is endemic in the Mediterranean region.

Heterochthonous[4] *faunas.*—In many cases faunas appear unheralded by local ancestors, having been brought in by migration from other regions.

Thus in America, according to Professor H. S. Williams,[5] the

[1] Quart. Jour. Geol. Soc. XVIII., 1862, 46.

[2] Am. Jour. Sci., III. Ser., Vol. XLIII., p. 57.

[3] Arktische Triasfaunen, p. 148 and Abhandl. K. K. Geol. Reichsanstalt Wien., Vol. VI., Part II., Second half, p. 7.

[4] From ἕτερος, *other*, and χθών, *land*.

[5] Cuboides Zone and its Fauna. Bull. Geol. Soc. Am., Vol. I.

Cuboides fauna is exotic, appearing suddenly in the Tully limestone at the base of the Upper Devonian; but in Europe the *Cuboides* fauna belongs to a genetic series, and is autochthonous.

The *Tropites* fauna of the Karnic stage, Upper Trias, is heterochthonous both in Europe, Asia and America, but the place where this fauna belongs to a genetic series is still unknown.

In the same way several of the faunas of the Jura and Cretaceous in California appear to be heterochthonous; some of these are known to be endemic in certain regions, others, on the contrary, are not.

CONCLUSION.

From the foregoing facts it will be seen that migration increases the struggle for existence by introducing forms into new conditions, to which they must adapt themselves, and that it also breaks up the established equilibrium and introduces new rivals, thus affecting autochthonous forms. Migration therefore works hand in hand with natural selection in killing off weaker forms, and changing the plastic ones by adaptation.

It is also clear that migration strengthens the geologic evidence of great changes in physical geography in past time. Regions that now are continents have certainly been seas, and seas have probably been continents.

Even the ocean abysses need not have been permanent, for their faunas have a modern aspect, and therefore must have changed from the old types. But from what we have seen of survivals of faunas under favorable conditions, we infer that without changes in conditions there is no reason why they should have changed. The natural inference then is that neither continental plateaux nor oceanic abysses have been permanent.

JAMES PERRIN SMITH.

STANFORD UNIVERSITY,
California, May, 1895.

Editorial.

THERE is nothing more remarkable in the whole range of geological history than the peculiar associations and successions of contrasted faunas and floras and of glacial beds and coal deposits in the southern portion of the eastern continent during the closing Palæozoic and opening Mesozoic eras. Scarcely less interesting are the shifting relations of faunas and floras and the implied geographic connections and disseverances of the ages which follow these and find expression in the eastern part of the same continent and the western portion of our own. The contributions of the last two or three decades from the circum-Pacific provinces have done much to break down current interpretations of geological history and to build up new ones. And there is doubtless more to come. In this field, with little question, lies the solution of many radical problems. It is therefore a matter of congratulation that, beside the work of the national and state surveys, two rapidly rising universities on our Pacific border are vigorously pushing geological inquiry and rapidly giving the public the benefit of their results. The nearly simultaneous offering of three papers relating to California geology, and the knowledge that others were in preparation, suggested the gathering of these into a California number of the JOURNAL, both as a means of concentrating interest and as a recognition of the richness of the field and the industry and ability of its workers.

T. C. C.

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In the editorial of the last number the words "and ten" on page 341 at the end of the fifth line from the bottom should be omitted.

PUBLICATIONS.

Note on Mr. Kümmel's Review of the "Reconstruction of the Antillean Continent."

MR. KÜMMEL'S review of the paper under the above title is of particular interest in calling attention to impressions which topics not considered by the author produce upon a conservative reviewer, somewhat hesitating in accepting the recently set-forth theory of great continental elevations, although willing to admit an equal amount of terrestrial movement, providing much of it be confined to the sinking of the floor of the sea. The startling character of the changes of level in late times has impressed itself upon none more than the author, for it took several years to overcome the prejudice against an apparent hypothesis which had not commonly entered into our literature. The papers so far published are only part of those ready, or in preparation, on account of extended researches in the West Indies and Mexico since the appearance of the paper reviewed by Mr. Kümmel. Concerning these investigations, it may be said that they not only confirm in a most satisfactory manner the conclusions reached at an earlier date, but they supply many deficiencies which were found in the preparation of the earlier work, and also carry the researches much farther than had been anticipated. These results will be offered in course of time to the public; but even with these published, the work must not be considered as scarcely more than commenced, for it is impossible to predict to what limits it will reach.

Mr. Kümmel says that the author makes no reference to sunken delta deposits, and therefore infers that they do not exist. Not at all. It is one of the several topics which along with the more important questions of the slopes of the drowned valleys, has not been discussed, and which the reviewer deprecates as not having been considered,—a point well taken. The slope of the sunken valleys ought not to be compared with those of the eastern part of the continent, but with those on the margins of the Mexican table lands and other regions within the tropics, while the declivities of the continental valleys of the

east are comparable with those occupying the interior of the plateaus. The descent of the canyon of the Colorado alone cannot be taken, but that of the reaches of the canyon and of the valley to where it emerges on the highlands of the Great Basin at an elevation of 7000 or 8000 feet. The descents of these valleys are not appreciated by their mean slopes, which in part are insignificant but in other places they are precipitous. It is necessary to analyze the details. Thus the writer has observed the descents of the existing land valleys through thousands of feet with characters and slopes comparable with those sunken across the sunken coast plains. This study will be brought out in detail.

Mr. Kümmel gives prominence to the hypothesis of the extraordinary sinking of the floor of the Mexican Gulf, etc., thereby accounting for the greater portion of the subsidence of the valleys. It is gratifying that the reviewer accepts the evidence of the changes of level to the same proportion as the author, although suggesting a somewhat different character. The question of determining the amount of local deformation of the continent as different from the general movement is doubtless one of the difficult points; but the author allowed any amount up to 4000 feet for covering the abyssmal subsidence in excess of the general movement south of the Mississippi. Whether too much or too little cannot yet be said. But amongst the Bahamas there is a better yard-stick. The drowned valleys reach to a depth of 12,000 or 14,000 feet, amongst islands, banks, and in the edges of the continental plateau, which last is submerged to no more than 4000 feet. Thus we cannot deduct for exaggerated marginal depression more than this amount in some places, and in others not even so much. However, the writer hopes to remove a few of the obscurities in the continental history, and thanks the reviewer for pointing out some of the greatest needs in elucidating the investigations of the great changes of level of land and sea, much new data being already at hand.

J. W. SPENCER.

Ueber Archaeische Ergussgesteine aus Småland. Von OTTO NORDENSKJÖLD. (Bull. of the Geol. Instit. of Upsala, Vol. I., No. 2, 1893, pp. 125.)

Of all rock names probably the most indefinite, and at times the most convenient, are the names: *greenstone* in America, *petrosilex* in France, *felsite* in England, and *hälleflinta* in Sweden. Many, and

often diverse types, have been grouped together by this means, and confusion has often resulted.

This paper of Dr. Nordenskjöld's forms a very important contribution to our knowledge of the Archæan rocks, and it adds new meaning to these abused terms. The Scandinavian peninsula has long been classic ground for Archæan studies, and nowhere is that formation better represented, or its problems more varied. Småland is a Baltic province comprising three districts of southern Sweden, and it is about twenty-five miles distant from Christiania. The surface occupied by the rocks described is over 10,000 square kilometers. In this paper the hälleflinta and porphyries are particularly described, and references are made to the preceding work of Eichstadt and Holst on the basalts, gabbros and other basic rocks. The term *hälleflinta* is a very old one, and designated a gneissoid, opaque rock which accompanied the ores. It was afterward applied to all rocks with a compact structure. A complete summary of the literature on this subject is given, and the progress in the knowledge of the true nature of such rocks is also pointed out. They were long regarded as of sedimentary origin. In 1877, Allport, in England, proved the Shropshire greenstones to be acid eruptives, and he was soon supported by the other English petrographers. Rocks similar to the Småland types were described by Irving in the copper-bearing series, by Williams in the South Mountain district, and by Sederholm in Finland.

The study of the Småland rocks was commenced by Nordenskjöld in 1889, and their eruptive origin first shown in 1892. In this area occur four belts of the *hälleflinta*, each 60 to 100 kilometers long and 10 to 15 kilometers wide. They contain neither glass nor microfelsite, and so cannot be classed as felsophyres or vitrophyres; further, they are identical with the South Mountain rhyolites. The granites of the area are both coarse and fine grained; the latter, or aplitic variety, grades into the *hälleflinta*, and it often contains dark basic patches. The porphyries occupy a position between the granites and the eovolcanics, but they are allied to both. The granophyres are closely connected with the Lönneberg eodacite, especially near Näshult, where the rock is rich in augite. Porphyritic dyke rocks occur in many places, but always in or near the hälleflint areas. They are identical with the massive porphyries, and they represent the last stage of the eruption. They occur by the hundred close together and parallel, but always separate.

The rocks so far described show but little variation, and they are mainly important in their transition to the next series of eovolcanics which cover nearly one-half of the area. The acid eruptives include the eorhyolites and eodacites which chemically are almost identicaf with the younger rhyolites and dacites. They possess a porphyritic structure and a black felsitic groundmass. All the rocks described in the paper show strong mechanical deformations, but chemical alteration of the minerals in this series is so rare that it is probable they were broken during their eruption. The structure is almost cryptocrystalline, and it varies even in the same thin section. A considerable number of accessory minerals occur and pseudomorphs are quite common. Epidote is present, as in the South Mountain rocks. In the eorhyolites eutaxitic structure is less common than in the other types. The groundmass is weakly doubly refracting and red in color due to hematite flakes. Among the pyroclastic rocks occur the volcanic equivalents of the porphyries. Quartz is rarely present, yet the rocks are more acid than the eodacites. Under the primary breccias are included the eutaxites and the agglomerate lavas, the former showing flow structure, the latter being fragmental. The agglomerates possess the rhyolitic structure of Rutley or the aschen structure of Mügge, which argues for a tuff-like origin. The absence of foliation and transition into the eutaxites speaks against this view, thus leaving the question open. Near Kolsjön occur fine examples of perlitic partings, spherulites and lithophysæ. The chemical work of Santesson shows no essential difference from the younger eruptives. The presence of manganese allies these rocks to the South Mountain types, and the high alkali percentage joins them with the keratophyres and dacites.

In age the rocks are pre-Cambrian. Sederholm divides the Archæan into three divisions: Katarchæan, Bottnian, Karelian (Algonkian). The Småland granites and hälleflinta are katarchæan and belong to the group of oldest known volcanics. There are no safe mineralogical distinctions between the eovolcanic and the younger porphyries, but there is a difference of habit. In the older rocks there is a greater occurrence of crypto-crystalline structure and less of the granophyric or microfelsitic arrangement. The boundaries of the mineral constituents are indistinct, and there is a greater number of secondary constituents. Spherulites and other characters also enter. The eruptive character of the rocks is proved by :

1. Absence of true stratification.

2. Order of crystallization.
3. Flow structure.
4. Implication structures (micro, and crypto-pegmatite).
5. Spherulitic structure.
6. Spheroidal (kugel) structure.
7. Perlitic partings.

The original appearance of these rocks cannot be described, for they have been completely altered by dynamo metamorphism and its attendant changes, among which devitrification has been most active.

Throughout the paper the prefix *eo*, as in eorhyolite, is used to show the relation of the old volcanic to the newer type with which it is closely connected. This brings in the troublesome age question in classification. At present there is a reaction against the use of age terms in petrography, and it would be better to employ the prefix *apo*, as suggested at nearly the same time by Miss Bascom,[1] and thus avoid the old discussions and objections. Dr. Nordenskjöld refers to this prefix in a note at the end of his paper, and signifies his willingness to adopt the *apo* prefix if it is regarded by petrographers as a better one.

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[Several reviews intended for this number are deferred to give place to standard articles.]

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